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Journal of the Council for Scientific and Industrial Research

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The Effect of the War on the East Australian Trawl Fishery

*By W. S. Fairbridge, M.Sc.**

Summary

The statistical data of the east Australian trawl fishery from its inception in 1915 to 1946-47 are assembled and analysed with especial reference to the decreased fishing effort during the war. The catch per trawler-ton-month is employed as the basic measure of abundance of stock since 1929. A comparison of the fishing effort expended at the present day with that of previous years is obtained by expressing the Danish seiners in trawler-tons. Though the data are somewhat heterogeneous they indicate rather strongly that, under present fishing conditions, a fishing fleet equivalent to 3,250–3,500 trawler-tons will maintain the stocks of trawl fish in a stable condition, but that a fleet larger than this is liable to depress the catch per unit effort and, ultimately, the total catch. It is pointed out that the total fishing effort in 1946-47 was about 4,600 trawler-tons and has increased subsequently.

The apparent "failure" of the chief species, the tiger flathead, in 1946-47, is discussed.

1. Introduction

Two wars within the last thirty years have produced effects in the heavily fished European fisheries which are well documented and now common knowledge among fisheries workers. Before the First World War many people had already been thinking that in the North Sea and some adjacent waters the same or possibly a greater total catch might have been made by fewer boats. The war showed that this was often indeed the case, particularly in the trawling industry. Hostilities provided a fallow period for the fishing grounds such as could hardly have been produced in any other way; fish stocks had a chance to build up; and when fishing was resumed, the total catch, but more particularly the catch per unit effort or rate of catch, rose spectacularly. The peak, however, was quickly reached and the catch per unit effort then declined more or less rapidly until in many cases it reached a lower level than before the war. The position in most of the European trawl fisheries during the interbellum was that catches per boat were low on the home grounds, the really good fishing was to be had only in the far distant areas, and there was a general feeling in the trade as well as in fisheries laboratories that the industry was overcrowded and that fewer boats could catch as much or more fish for the public,

* An officer of the Division of Fisheries.

and at the same time make a better living for the men in the industry. Regulation of the fishery in European waters is, however, enormously complicated compared with Australian conditions, by reason of the several nations seriously involved, and the far more complex pattern of the fishing grounds; the prospect of unemployment among the fishermen was at that time another deterrent to limiting the fishing fleets. As a result, little was done.

At the same time, as documentation and research in fisheries developed in other parts of the world, it became evident that overfishing was occurring elsewhere and was, in fact, liable to occur in any fishery where the product had a ready and payable market. A steam trawler is expensive and must be kept constantly at work to pay overhead expenses; as a consequence, when catches begin to fall off, either through overfishing or a natural adverse fluctuation in stock, the tendency is not to lay trawlers off, but to work them more efficiently and for longer hours in an effort to make up the leeway and in the hope that things will improve.

Reports of the effect of the Second World War on European fisheries are now coming to hand. As expected, the history of twenty years ago is being repeated. One of the most convincing and spectacular accounts in Hickling's (1946) of the hake fishery, where in 1942 and 1943, 39 per cent. of the pre-war fishing fleet took more than the 1937-39 average, and the catch of fish per gross ton of trawlers had risen from about 25 cwt. to 61 cwt. in 1945. It is not, of course, suggested that such a performance could be maintained—many of the grounds had been more or less completely rested for a matter of years and the boats were working on an accumulation of older and larger fish. Such accumulations are also found on virgin grounds, and this presumably happened with the New South Wales trawl-fish stocks thirty years ago. When heavy fishing begins or is resumed on such stocks, phenomenal catches are often made; Herlihy (1927) reports a catch of 1,117 baskets of edible fish in 36 fishing hours by the State trawler *Brolga* in March 1919, and a similar catch again in March 1921. But the high levels of catch per boat are not maintained for long, and this was particularly the case in New South Wales, where already highly developed and fully mechanized equipment was suddenly brought to bear on virgin stocks.

However, a study of the changes in catch and rate of catch that go on during periods of recovery or intensification of fishing can often throw much light on the question of what level of fishing intensity is suitable in any given fishery. Hickling has done this in the case cited above, and has arrived at an estimate of the fishing intensity which will produce a high but steady catch. This is not the "optimum catch" of Russell (1942), which involves the optimum *size* at which the species should be caught; but the calculation of the optimum catch requires a very complete biological and statistical background, and has not, in point of fact, been made yet for any fishery. In default of this material, it was thought that a study, largely statistical, of the east Australian trawl fishery might give some indication of a suitable level of fishing for this fishery; urgency was lent to the question by suggestions that the pre-war level of fishing might have been reduced with advantage, and that the level of fishing to-day is higher than ever before.

Though this study is primarily statistical, it should be pointed out that a fairly intensive study of the biology of the chief species (tiger flathead) has been carried out now for some years, and though the results are not sufficiently complete for publication, the general features of its life-history and growth are fairly definitely established, and have been borne in mind in making the recommendations at the conclusion of this paper.

2. The Argument of the Paper

From the foregoing and from general arguments it follows that when an active fishery ceases, and then resumes, the catch per unit effort will be high at the first resumption—except insofar as this may be obscured by an adverse natural fluctuation. The degree of recovery will depend on (*a*) the intensity of fishing before fishing stopped, and (*b*) the speed of recruitment to the stock, by increase in numbers of young fish and by the growth of the existing older fish minus loss from natural mortality, all in conjunction with the length of the rest permitted the stock of fish. Assuming adequate time is allowed for the stock to build up, the degree of recovery should be some indication of whether the stock was being underfished or overfished.

It will be shown in this paper that during the recent war the eastern Australian trawl fishery was given ample time in which to build up stocks, but that the increase in the catch per unit effort during and immediately after the war was not of an order to suggest that there was heavy overfishing before the war. At the same time the evidence points strongly to overfishing in 1929, and attention is therefore drawn to the fact that the level of fishing intensity in 1946-47 was higher than in 1929, and shows every indication of rising higher still. A stable level of catch is found to have occurred with a fishing intensity of about 3,250–3,500 trawler-tons, and it is suggested that, though this may not be the optimum fishing intensity, it is most probably close to the maximum which the fish stocks can support under present conditions.

3. The Fishery

Colefax (1934) gives an account of the fishery, with a figure of the main trawling areas, and compares in detail the catches of 1918-22 with that of 1930.

As concerns the present paper, the salient features in the history of the fishery are as follows:

(i) Trawling was begun by three boats in 1915 under State ownership, augmented to five by 1919, and discontinued in 1922. During the early years the grounds had to be explored, the habits of the fish learnt, and to a certain extent the crews trained. By 1919 the main grounds from Newcastle to Green Cape were being worked, at depths mostly of 40–80 fathoms, and the chief fish, flathead, had been popularized on the market. It is a feature of the New South Wales continental shelf that the bottom inside the 30 fathoms line is mostly steep and rough, likewise the edge of the shelf, and both are impossible to work with trawling gear.

(ii) In 1923, the State trawlers were bought by private firms.

(iii) About 1925 and 1926, Vigneron-Dahl extension gear was introduced; this gear is a modification of the otter trawl, which Hickling (1931) found to give an average increase in efficiency of about one-third, though there were very wide fluctuations in efficiency varying from actual loss to increases of 100 per cent. or more, the increased efficiency being greatest when fishing was best. In the same years new vessels began to come out.

(iv) After 1930, the last important extension to the New South Wales grounds began to be fished—the eastern Bass Straits grounds, Cape Everard, and Babel Island.

(v) From 1937 Danish seine motor vessels began to come into the industry, their numbers (licenses issued) increasing from 4 or 5 in 1937 to over 50 in 1942.

(vi) At the outbreak of war in Europe the trawlers began to be requisitioned by the Navy; but the number of Danish seiners continued to increase until the Japanese war, when almost all were requisitioned by the Australian and United States Services. Many of the crews also left for service in the small-ships employed to the north of Australia. In the latter half of 1943, these boats began to be of importance again, and their numbers rose phenomentally in 1944-45, and again in 1945-46 as a result of building and of Services' vessels being returned or resold. In these years they had the trawl fishery virtually to themselves, there being only one trawler in 1943 and 1944, and gradually increasing numbers from then on.

In the following account the species of fish taken in the trawl fishery will be referred to by their popular names. For the benefit of overseas readers, therefore, the scientific names of the most important species are now given in their approximate order of importance:

Tiger flathead—*Neoplatycephalus macrodon* Ogilby.

Morwong—*Cheilodactylus macropterus* Bloch and Schneider.

Nannygai—*Trachichthodes affinis* Günther.

Gurnard—*Pterygotrigla polyommata* Richardson, also *Chelidonichthys kumu* Lesson and Garnot.

Leatherjacket—various Monacanthidae.

Also mentioned in the text, is the barracouta, *Thyrsites atun* Euphrasen. The names skate and shark denote very much the same groups of Elasmobranchs as in Europe.

4. The Statistical Material

The total catch statistics of this fishery are of particular interest because they go back to its very inception in 1915. Unfortunately, the story is in some other ways incomplete. The early years (1915-1922) are covered by Herlihy's report (1927). The weights of fish

were calculated from the numbers of baskets unloaded from each vessel. These figures may be questioned as being too low—more fish being actually unloaded than reported.

There are two main sources of information for the subsequent history of the fishery; firstly, the Maritime Services Board (earlier the Sydney Harbour Trust) gives the weight of fish landed in Sydney Harbour, their figures for 1923-1927 being obtained by an investigation of the books of the trawling companies, and for later years from the ships' manifests lodged by the shipowners; secondly, the Annual Reports of the New South Wales State Fisheries Department, which give the weights of trawled fish sold at Newcastle and the Sydney Municipal Fish Markets for each year up to 1940-41, from which date their annual totals are made up from the monthly returns furnished by the steam trawler companies, and the owners of the Danish seine vessels. These two sets of figures are compared in Table 1. In detail they disagree—the Fisheries Department figures tending to be higher than those of the Maritime Services Board after 1929, but the overall picture is in very good agreement, and since the two sets of figures are of independent origin, they act as a valuable check on one another. The M.S.B. figures probably give an accurate picture of the fish landed at Sydney, but do not take account of the fish landed at Newcastle in the early years, or of recent fishing by Danish seiners, which land the bulk of their catch at harbours along the coast.

On the other hand, the Fisheries Department figures since 1941-42 are dependent upon the accuracy with which the monthly returns are filled in. There is as yet no law enforcing an owner to supply these returns, or to make them accurate. To the end of the war the Danish seiners' returns are probably complete, and reasonably accurate; since then, however, some boats have not been making returns, and those returns which were made out tended to under-estimate the catch for various reasons. The M.S.B. figures, for the trawlers are still, however, a valuable independent check on the monthly returns.

By and large, we have a good picture of the trawler catch from the M.S.B. figures for the war and post-war years, but estimates of the Danish seine catch are low, at least after 1945.

One other source of information is the logs of the State trawlers, and some logs from the private companies for the years 1936-1941 (Table 2), supplying the catch per hour. There is also the log of a single vessel of 271 tons, giving the catch per day's absence from port for the years 1927-1934 (Table 3).

5. The Total Catch

The study of a mixed fishery such as this should deal with the various species individually, or at least with the main species. This is not possible with the material available, save in the later years, and the fishery will therefore be treated largely as a whole.

The general course of the total catch is clear from Fig. 1A (continuous line). This graph is derived from different sources: Herlihy's report was used for the early years; the M.S.B.'s figures were used for 1923 to 1927; from then to 1934 the same source was used, but adding the fish sold in Newcastle as given by the State

Fisheries Reports; from 1936 there is a big discrepancy between the M.S.B. and State Fisheries' figures, and the M.S.B. figures are therefore shown by the dotted line which may be taken to represent the catch by the trawlers, while the continuous line is now drawn from the State Fisheries' Reports, and after 1937 reflects the catch by the Danish seiners. The use of a mixed source of information for deriving the graph of total catch may be open to criticism; but it is felt that, as drawn, the graph does reflect more accurately the true history of the fishery than either source taken singly, and, as previously mentioned, the two main sources of information are independent and in good agreement, except perhaps for 1936 and 1937, as may be seen from Table 1.

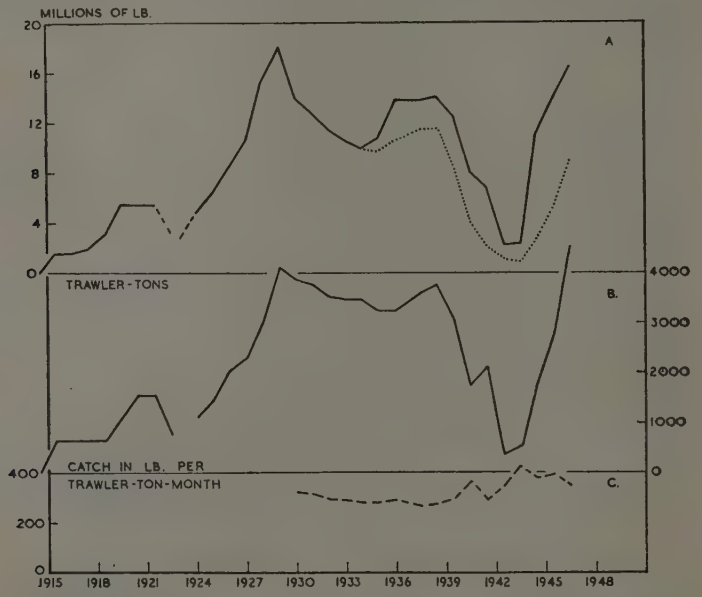

FIG. 1.

A.—Annual total catch of trawl fish. The dotted line represents the catch by the trawlers only, as given by the M.S.B. figures. The continuous line after 1937 includes the catch by the Danish seiners.

B.—Total fishing effort, by trawlers and Danish seiners, expressed in trawler-tons.

C.—Catch per unit effort by trawlers only (see Section 6).

Examining now this curve of total catch, the level is depressed in the very early years by the vessels spending part of their time minesweeping, as well as by the necessity to learn the grounds, the foul bottom and the habits of the fish, and to train skippers and crews. In addition, it is suggested that the figures supplied may be lower than the real catch; it is certain that some fish was being dumped as a result of gluts on the then limited market, and that active fishing was

occasionally curtailed for the same reason; all these factors would make the fish appear scarcer than they were. Reference has already been made to some enormous hauls made during this period.

After the break in 1923, when the private companies took over, there occurs the swift and steady rise typical of a virgin, expanding fishery; this may be compared with Russell's (1942) account of the Pacific halibut, the Norwegian prawn, and the North Sea trawl fisheries in his Chapter I, and the English plaice fishery in the Barents Sea, pp. 77-81. From this point the catch declines to 1933 or 1934, partly as a result of a reduction in the number of trawlers, partly owing to a fall in the actual catch per trawler as shown by the catch per trawler-ton-month. Subsequently, there is a rise, at first due apparently to a natural recovery by the fish stocks, but sustained in

TABLE 1.—CATCH BY TRAWLERS, DANISH SEINERS, AND CATCH PER TRAWLER-TON-MONTH

(*All weights of fish in lb.*)

—	Steam Trawler Catch M.S.B. Data	Trawler-Ton-Months	Catch per Trawler-Ton-Month	Total Catch M.S.B. Figures	Danish Seiners' Catch Monthly Returns	Total Catch Fisheries Department Figures
1915–16 ..	1,630,380					
1916–17 ..	1,637,070					
1917–18 ..	1,897,650					
1918–19 ..	3,023,640					
1919–20 ..	5,585,160					
1920–21 ..	5,527,140					
1921–22 ..	5,404,680					
1922–23 (8 months)..	3,258,240					
1923 (5 months)..	2,867,200	..	..	2,867,200	..	1,431,607
1924 ..	4,813,760	..	..	4,813,760	..	5,302,155
1925 ..	6,316,590	..	..	6,316,590	..	7,694,757
1926 ..	8,461,600	..	..	8,461,600	..	6,681,251
1927 ..	10,673,600	..	..	10,673,600	..	10,673,600
1928 ..	12,785,920	..	..	12,785,920	..	11,682,450
1929 ..	14,693,000	..	..	15,016,600	..	15,076,600
1930 ..	12,006,566	43,146	323*	13,110,526	..	14,219,937
1931 ..	11,421,412†	40,668	314*	11,422,182	..	11,436,182
1932 ..	10,285,625	38,745	296*	10,285,625	..	11,740,708
1933 ..	9,576,260	36,194	291*	9,721,495	..	9,721,495
1934 ..	8,860,740	34,753	279*	9,016,140	..	9,905,510
1935 ..	9,772,350	34,750	281	10,042,760	..	10,794,484
1936 ..	10,539,340	36,092	292	10,759,910	..	13,834,170
1937–38 ..	11,308,150	41,738	271	11,543,140	..	13,716,990
1938–39 ..	11,350,850	41,467	274	11,570,160	..	14,089,440
1939–40 ..	8,477,560	28,434	298	..	..	12,387,144
1940–41 ..	3,856,580	10,527	366	..	..	8,043,180
1941–42 ..	2,119,430	7,317	290	..	..	6,862,800
1942–43 ..	1,131,070	3,290	344	..	991,392	2,240,062
1943–44 ..	902,990	2,133	423	..	1,199,092	2,275,140
1944–45 ..	2,797,830	7,393	378	..	8,215,503	10,069,807
1945–46 ..	5,416,528	13,734	394	..	8,603,202	12,791,875
1946–47 ..	9,061,380	26,127	347	..	7,164,798	16,226,178

* Adjusted to include fish landed at Newcastle.

† The original figure included no data for September and has therefore been raised by one-eleventh.

1937 by the new Danish seine vessels entering the industry. The height of the peak shown in 1936 is suspect. In 1937-38, Danish seine vessels began to enter the fishery and raise the total catch; in that and the two following years, the number of licences issued was 5, 6, and 10, which (assuming all boats fished actively) could account for only some 800,000 to 1,000,000 lb. per year, so that in view of the trawler catch as given by the M.S.B., the total catch for those years is also somewhat suspect. The writer is of the opinion that the best estimate would be by taking the M.S.B. figures for these three years and adding the suggested Danish seiners' total, making a peak in 1938-39 of about 12,400,000 lb. In any event, both sets of figures show the fall in catch which began as soon as war in Europe was declared, and was accentuated when the Pacific war broke out.

Recovery in 1944-45 was very swift, the small-ship building industry on the New South Wales coast having been greatly developed by war contracts, and receiving protection and encouragement from the authorities with a view to increasing the local food supplies by fishing. As previously suggested, the 1944-45 figure is accurate, but for the next two years is probably low, owing to under-estimation of the Danish seiners' catch. In the latter years, however, steam trawlers were undoubtedly recovering much of the ground lost to the Danish seiners.

To sum up, till 1935 or 1936 the fishery follows a very typical course and might indeed be used as a model in the development of a fishery; after a period in which initial difficulties are overcome, there is a swift and steady rise to a peak, from which there is an almost equally swift decline, due in part to a fall in catch per vessel. After 1936 there is a rise in catch, assisted by the introduction of a new gear —the Danish seine. The full effects of this new gear are marked by the sudden fall, almost to zero, caused by the Second World War, and the subsequent extremely swift recovery to a peak which rivals that of 1929.

6. The Catch by the Steam Trawlers

Where the question is one of conservation, we are interested in the total catch more as a step towards calculating the catch per unit fishing effort than for itself. The catch per unit fishing effort is probably the best available measure of the marketable stock of fish in the sea, and it is the fish stocks which are of interest to the conservationist.

In the present section, the catch of the steam trawlers will be examined, and for this the Maritime Services Board figures, adjusted to take in the fish landed at Newcastle in some of the early years, will be used almost exclusively. These figures represent virtually the whole of the catch by the steam trawlers; and from 1930 onwards they are particularly useful since they give the individual monthly catch by each trawler, and from this the catch per unit effort will be calculated.

The almost universally used unit of fishing effort for trawlers is the "fishing-hour" or failing that, the "days absent from port". Neither of these units is available in the present case, save rather

incompletely and for disconnected periods which will be dealt with later, and we must, therefore, rely on the "trawler-month" or better, the "trawler-ton-month". The simple nature of the fishery and the sharply delimited trawling ground of the eastern Australian shelf, along the whole length of which trawling is carried out every year, should help render this unit a useful and fairly consistent measure of fishing intensity. Moreover, in later years, there has been only one port, namely, Sydney, from which these vessels fish.

The factors which tend to make the unit inaccurate are: the varying periods of lost fishing time due to spells in dock for overhaul, maintenance and so on, which may affect some vessels more than others; the variable weather, which may be particularly bad or the reverse in one year or a series of years; the time lost in steaming to fishing grounds, which may be less in some years if the home grounds become prolific, or more if the skippers choose to frequent the distant grounds. As regards this last factor, the trawling grounds extend north from Sydney about 250 miles to Crowdy Head, and south about 550 miles to Flinders Island, representing maximum steaming times of about 25 hours and 55 hours; in practice, a vessel seldom steams direct to these outlying grounds, but has a "dig" with the trawl at one or more points en route, stopping wherever the fishing is good. Lundbeck (n.d.) compares the travelling times to the various main fishing grounds of the Wesermünde trawlers; it is instructive that he should find it satisfactory to group the whole North Sea together, distinct from the Kattegat, Iceland, Barents Sea, and Bear Island; laid on a map of the North Sea, the longest steaming distance of the New South Wales trawlers would reach from Wesermünde to a line joining Newcastle (England) and the southern tip of Norway—that is, enclosing an area of not much more than half that of the North Sea trawl fishery. Moreover, the trawler-ton-month will be compared over a period subsequent to the opening of the Flinders Island ground and after the period of extremely prolific fishing on the home grounds had ended; in other words, any changes in the catch per trawler-ton-month will not be due to the opening up of new grounds, and from general information we know that fishing has been spread fairly regularly over the grounds (save for the Cape Everard-Flinders Island ground during the war), and since there is a direct continuity of a hydrological and ecological nature along the length of the fishery, it would be unreasonable to suppose any sudden fluctuations in the stock of different areas in the absence of evidence for them. As regards the weather factor, nothing can be said save that isolated years of good or bad weather would not have the sort of effect on the catch per trawler-ton-month that might be mistaken for a fluctuation in fish stocks, and that sequences of particularly stormy years or the reverse are not a recognized feature of this coast. The varying periods spent idle in port is perhaps the most serious of the three possible sources of error; for instance, it is possible that trawlers to-day spend less or even more time being serviced or repaired after breakdown than they did one or two decades ago. But it is thought that losses of time due to serious breakdown and overhauls will be largely allowed for by counting only the months during which there was some fishing; and as regards the routine "turn around" time between trips, it is unlikely that there has been much change over the years.

In all, it is felt that this unit is a consistent, although somewhat insensitive, measure of the availability of the fish, and this is borne out by the consistency of the graph in Fig. 1c, where the catch per trawler-ton-month is shown for comparison both with the total catch, and with a rough measure of the total fishing intensity (see later, pp. 91 *et seq.*).

The catch per trawler-ton-month has been calculated by dividing the total annual catch of the trawlers by the sum of the products of the gross tonnage and number of months each vessel was working. Fractions of months cannot accurately be allowed for, but presumably vary in a random manner. The question of including in this sort of calculation the factor of gross tonnage of the trawlers has been dealt with by Hickling (1946). Since the Australian steam trawlers are identical types and use the same gear as in the Irish hake fishery, his conclusions are no doubt valid here. Nevertheless, correlation coefficients of catch on gross tonnage were calculated for between 17 and 13 trawlers for the years 1930, 1934, 1936, and 1938, and were found to be $+0{\cdot}56$, $+0{\cdot}28$, $+0{\cdot}40$, and $+0{\cdot}38$ respectively. All but the first of these are below the 5 per cent. level of significance and are much lower than Hickling's figure of $+0{\cdot}939$ (due in part no doubt to the smaller range of tonnage in the present material, and to the greater scatter resulting from the use of the catch per fishing month, rather than the catch per hour's fishing); nevertheless, they are all positive, demonstrating that it is necessary to take into account this factor of tonnage. The trawlers used for these calculations were not all working in every month each year, but this should not bias the results since the catch of total fish shows little seasonality, (although, as mentioned elsewhere, the flathead catch is somewhat seasonal). From a scatter diagram of this material, it is quite impossible to say whether there is a straight line regression, but since these tonnages fall within the range of Hickling's much fuller material, it is safe to assume so.

The trawler-ton-months and the catch per trawler-ton-month are set out in Table 1, alongside the steam trawler catch as given by the Maritime Services Board. A number of aberrant vessels—the *Palmerston, Pelican, William Combe, Unique, Bucra,* and *Nanagai*—which could not reasonably be compared with the other trawlers, have been excluded from the trawler catch, and their catches account for the difference between this column and that giving "Total Catch: M.S.B. Figures". For the years 1930-1934 the catches per trawler-ton-month have been adjusted to include the weight of fish sold in Newcastle, as given by the State Fisheries Department's Reports for those years; the quantities of fish involved vary from nearly 2,000,000 lb. in 1930 down to 800,000 lb. in 1934. The vessels concerned took turn about in landing fish at Newcastle, one or two vessels unloading there each week, so their tonnages would be shown in the trawler-ton-months column as landing fish also in Sydney, and their entire catch ought, therefore, to be accounted for.

The actual course of the catch per trawler-ton-month, shown in Fig. 1c, will now be examined. The catch per unit effort is best considered in three periods: the earliest years till 1929, for which no precisely comparable figures are available; the period 1930-1939; and the war and post-war years to 1946-47.

This first period includes that during which virgin stocks of fish were being worked. We have no figures for catch per trawler-ton-month, but the catches were certainly very high. Tables 2 and 3 include for some of these early years the catch per hour's trawling and the catch per day's absence from port as extracted from the logs of certain trawlers (the figures for 1930 are taken from Colefax, (1934) and refer to one company only). These units of rate of catch have been used so widely in fisheries research that it is unnecessary to comment on them, but it should be noted that where figures refer to a part of a year only, they should be treated with caution, because, the flathead fishery being somewhat seasonal, such figures could be most misleading. From Table 2 it is evident that the rate of catch

TABLE 2.—CATCH IN CWT. PER HOUR'S TRAWLING

Year	Number of Vessels	Flat-head	Other Species	Total Fish	Year	Number of Vessels	Flat-head	Other Species	Total Fish
1918	3	2·3	0·5	2·8	1936	2	1·7	..	..
1919	7	3·9	0·5	4·4	1936–37	5	1·4	..	..
1920*	6	5·7	1·1	6·8	1937–38	14	1·3	1·3	2·6
1921	6	4·4	0·8	5·2	1938–39	5	1·2	1·3	2·5
1922	7	4·1	1·0	5·1	1939–40*	8	1·3	0·8	2·1
1923*	7	4·4	1·2	5·6	1940–41*	6	0·8	1·3	2·1
1930	..	2·5	0·5	3·0	1941–42	4	1·0	1·3	2·3

* Part of year only.

TABLE 3.—CATCH IN CWT. PER DAY'S ABSENCE FROM PORT

Year	Number of Vessels	Flat-head	Other Species	Total Fish	Year	Number of Vessels	Flat-head	Other Species	Total Fish
1927	1	45	4	49	1937	7	13	5	18
1928	1	40	2	42	1938	7	16	5	21
1929	1	30	5	35	1939	7	16	5	21
1930	1	22	6	28	1940	4	16	5	21
1931	1	21	5	26	1941*	2	11	8	19
1932	1	22	7	29	1942*	2	8	7	15
1933	1	15	8	23					
1934*	1	19	..	..					

* Part of year only

during 1918-1923 was at least double that of 1935-1942 for total fish and about quadruple for flathead. Table 3 shows the rate of catch still high in 1927 but declining to nearly half by 1930. This early period is looked back upon by the older trawlermen as the palmy days of New South Wales trawling.

In the second period there is a steady decline in catch per unit effort—a decline which Table 3 shows had begun at least by 1927, and which flattens out at about 1933 and then remains fairly steady till the war.

It is evident, therefore, that the rate of catch in this fishery has risen from an earlier low level to a peak, and, has then declined till it reached a steady but even lower level. This is in general agreement with other fisheries, and with Graham's (1939) theoretically derived sigmoid curve for the yield of a fishery with increase of fishing intensity. Though the peak in the curve of rate of catch would be higher than can be maintained under present conditions of unrestricted mesh-size and unrestricted fishing area, it is of some interest to calculate what that level was, and the fishing intensity at the time. This may be done by graphing the total gross tonnage of trawlers against their total catch (cf. Hickling 1946, Fig. 10). In Fig. 2 it is seen that the points fall on a curve. This curve may be regarded as two straight lines: the first, representing low trawler tonnages and showing a steady increase of catch; the second, representing high trawler tonnages, and having a very much flatter slope resulting from a decrease in the early rate of rise. A regression coefficient has been calculated for the first, and the fitted straight line drawn; it is clear that the points representing high fishing intensity fall well below it. The figure has been drawn from the data in Table 6, p. 93, for the years 1924 onwards, and omitting 1928 and 1939-49, in which calculation of the total trawler tonnage would have been too uncertain owing to lack of information as to what period of the year trawlers entered or left the industry. These two years might have helped fill in the point of inflection of the curve; but even in their absence it is evident that this point falls at a fishing intensity of about 2,500 tons and a catch about 9½ million lb. From this point onward, the catch per unit effort declines as the fishing intensity rises. From Fig. 1 we see that such a fishing intensity occurred between 1926 and 1927, and that the total catch then was indeed about 9½ million lb. This is moreover in agreement with Table 3, where the rate of catch is seen declining from 1927.

The first (expansive) period in the catch per unit effort extends therefore from the start of the fishery to 1926-27; the second period is one of decline to a stable level of a little less than 300 lb. per trawler-ton-month, or (from Table 3) 20 cwt. per day's absence from port. The total catch is falling from 1929 to 1934, but this is in part due to the fall in fishing intensity, and in 1936 there is even a slight rise in rate of catch; but this is followed by a fall to the lowest level recorded—a fall which could hardly have been due to the entry of the Danish seiners.

It would have been interesting to determine the effect on the catch per trawler-ton-month of this influx of Danish seiners, but by 1939-40 the effect of the war was masking any such development. With the consequent fall in fishing intensity there was an immediate rise in the catching rate. The very high and low figures for 1940-41 and 1941-42 are possibly real, and not due merely to the smaller numbers of trawlers from which the mean figure is drawn. By 1942-43 there was but one trawler working, and a few Danish seiners, and the trawler rate of catch reached its peak in 1942-43, and was sustained for two further years. By 1945-46, with about nine trawlers working and up to 80 Danish seine boats, under the influence of an adverse fluctuation in the flathead stock (see pp. 95-7), the trawlers' catch per unit effort began to decline towards its pre-war level.

Finally, some further observations may be made on the catch per hour's trawling as set out in Table 2, and the catch per day's absence in Table 3.

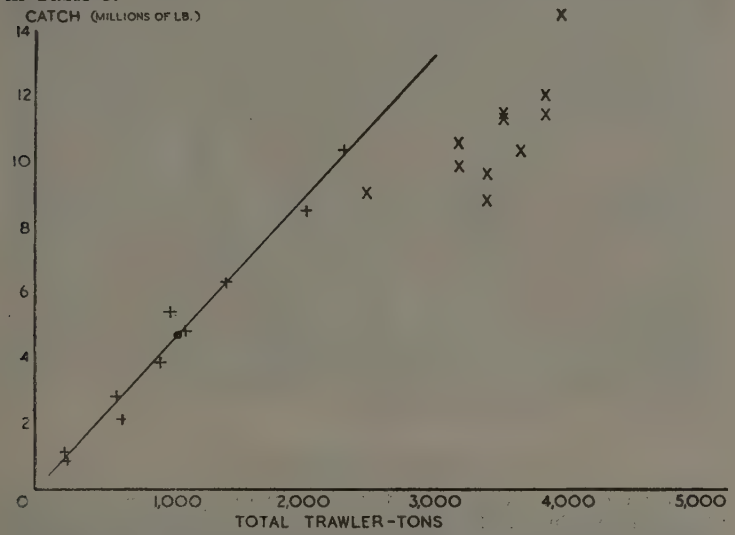

FIG. 2.—Relation between catch and fishing effort. Catch given in millions of lb.; fishing effort given by total tonnage of trawlers operating in each year. Rectangular crosses indicate years of low fishing effort, diagonal crosses years of high fishing effort; the regression line for the former is drawn.

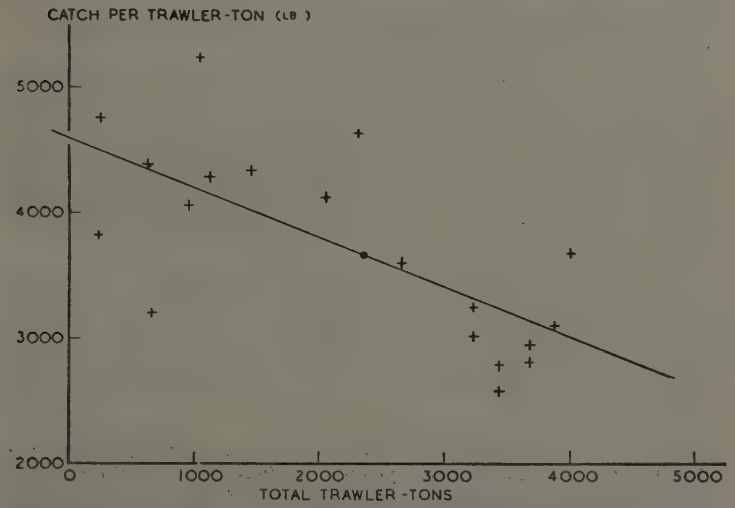

FIG. 3.—Regression of rate of catch on fishing effort. Rate of catch given in lb. per trawler-ton; fishing effort given by total tonnage of trawlers operating in each year.

As previously noted, the rate of catch of flathead in the very early years (Table 2) was almost quadruple that of the pre-war period, yet the catch of other species was only about the same, or a little less. For the flathead, this is probably a true reflection of the availability of the fish; but for the other species, much was undoubtedly wasted in the early days which is salable to-day. The process of popularizing previously valueless fish has gone on progressively over the years—morwong, nannygai, gurnard, barracouta, and during the war, skates and sharks, coming more into favour and being retained by the trawlers on those occasions when they were taken, and in the case of morwong, actively sought after when flathead was " off ". Presumably, therefore, the optimum catch of total fish is higher to-day than previously, but it seems likely that the limit has now been reached, and that very little is thrown away to-day which is at all edible. The habit of retaining more and more mixed fish is well shown in Table 3, where the rate of catch (and retention) appears to be rising to a maximum somewhere between 1933 and 1936. The subsequent fall suggests that the stocks or these fish (mostly morwong and nannygai) were reacting to the more intensive fishing which would have resulted from the skippers actively seeking out concentrations of those species in the " off " periods for flathead.

7. The Catch by Danish Seiners

The number of licences issued for Danish seiners since their entry into the fishery in 1936-37 is given in Table 6. As regards the figures since 1941-42, it is known that there were more licences issued than there were boats actually working at any one time, since licences were taken out for boats under construction and for prospective boats, and the same is at least partly true for the earlier figures. The licence figures do show, however, the rapid development of this type of fishing after 1939-40, rising to 53 in 1941-42, falling to 19 in 1942-43, and then rising rapidly again to 123 in 1946-47.

An estimate of the average number of vessels actually working in each month for the years after 1941-42 is given in Table 4. Neither the monthly returns nor the inspectors' reports give complete lists of the Danish seiners working each month, but by making a comparison of the two lists an estimate for each month has been arrived at, which would be a minimum figure, but is thought to be not more than 10 per cent. in error in any case; the average for the year has been derived from these estimates.

It is greatly to be regretted that there are no detailed figures for catch per boat before 1942-43. After that date we know the catch of each species per month, for those vessels whose owners filled in returns. In Table 4 are set out the catch of flathead and total fish per boat-month, along with the estimate of the average numbers of vessels working in each month of the year, and the equivalent catch by the trawlers.

The boat-month is considered adequate here as a standard measure of fishing intensity for the few years considered and for the uniform type of equipment. However, large vessels of 60-65 ft. overall do have some advantage over the smallest of 45 ft. by reason of the greater ease with which they travel north and south along the coast

in search of good fishing, and by being able to work in slightly worse weather. A progressive increase in the average size of the boats might tend therefore to elevate the catch per boat-month; however, this effect is probably slight as yet, save in 1943-44, when the average performance of the boats was probably very low, since these consisted of any vessel not requisitioned for the war, which would float and which could possibly be adapted to Danish seining. The catch per boat-month for this year is little more than half that of the following—a performance in direct contrast to that of the only trawler fishing at the time.

TABLE 4.—THE CATCH PER UNIT EFFORT BY DANISH SEINERS AND TRAWLERS OF FLATHEAD AND TOTAL FISH

(Data from Monthly Returns)

	Estimated Monthly Average of Danish Seiners Working	Danish Seiner Catch per Boat-Month.		Trawler Catch per Trawler-Ton-Month	
		Flathead	Total Fish	Flathead	Total Fish
		lb.	lb.	lb.	lb.
1943–44	10	5,043	9,017	237	504
1944–45	36	11,321	17,064	142	375
1945–46	57	6,343	12,058	130	443
1946–47	67	1,006	9,731	82	355

As mentioned before, the figures supplied by the Danish seiners are probably an under-estimate for the latter half of 1945-46 and again in 1946-47, though there is no reason to suppose that the ratio of flathead to total fish is inaccurate. As supplied, the figures in Table 4 show what must have been excellent fishing in 1944-45, dropping rapidly to 1946-47. It might be supposed that this fall is merely a reflection of such an under-estimate; but it is of such magnitude that there can be no doubt there has been some very considerable fall in rate of catch; moreover, in 1945-46 all Danish seine fishermen were commenting on the scarcity of fish compared with the previous year, and fishing was noticeably worse again in 1946-47 so that vessels began to leave the industry and representations were made by fishermen to the State Fisheries Department as to whether something could not be done to protect the stocks. It is evident that the fall in total catching rate is due largely to a fall in respect of flathead; the rate for other species (total fish minus flathead) being approximately 4,000 lb., 6,000 lb., 6,000., and 9,000 lb. for the four years.

Also in Table 4 are presented the flathead and total fish catch per trawler-ton-month of the few trawlers working. These figures again do not perhaps present an absolutely true picture, not because of any inaccuracy, but because they refer to only 1, 2, 5, and 9 vessels in the four years respectively, and no doubt the idiosyncracies of individual vessels are apparent in the first two years. However, the

fall in rate of catch of flathead and increase in rate of catch of other species (morwong and nannygai) is amply confirmed by verbal reports from the industry. The figures have been arranged alongside the rates of catch by the Danish seiners, because in respect of flathead they can be regarded to some extent as confirming the Danish seiners' figures. Finally, the greater stability in rate of catch of fish from year to year may be noted in the trawlers.

8. Recovery and Suggestions for Conservation

The outstanding result of the foregoing analyses of the trawl-fishery statistics is the demonstration of a rise in the rate of catch by the trawlers, which may have begun in the first year of the war (though the rate of catch was actually rising slightly at the time of the outbreak of war), but was unmistakable in the second year, lapsed badly in 1941-42 for no apparent reason, reached a peak in 1943-44—50 per cent. higher than the steady pre-war level, and fell slowly thereafter, being in 1946-47 still 23 per cent. above the pre-war level in spite of an apparent "failure" of the chief species (flathead) and a total fishing intensity greater than had ever before been exerted on the fish stocks.

A partial explanation for this rise in rate of catch has already been mentioned: the retention since the outbreak of war of fish species previously discarded. From enquiry in the trade it appears that the two secondary species, morwong and nannygai, were retained from the early days, though nannygai were inclined to glut the market at times and might then be avoided; leatherjackets were also inclined to occur in over-supply. But from "about 1931 onwards", when the rate of catch had fallen very low compared with the previous decade, very little was discarded except small gurnard, Elasmobranchs, and at times barracouta and leatherjackets. (It is significant that that year, which was quoted to the author, should agree so well with Table 3 in this paper.) It was not until 1944-45 that the trawlers began to detail the species taken, other than flathead; if, however, we sum the quantities of barracouta, flake (Elasmobranchs), and gurnard for subsequent years, we find that these species amount to only 9, 5, and 8 per cent. of the totals for 1944-45, 1945-46, and 1946-47 respectively. In the monthly trawler returns there is a column entitled "Other Species" which approaches in importance the sum of the three classifications mentioned above; however, the author understands that here again the species included are ones that have been retained at any rate over the last ten or fifteen years. Since some, at the very least, of the barracouta and gurnard were retained in the pre-war period, it can be safely concluded that not more than 5–10 per cent. of the catch during the war and to-day consists of species previously discarded.

A second possible explanation for the rise in rate of catch with the wartime decrease in fishing intensity, is that when fewer vessels are working there is simply "more to go round", each vessel obtaining a greater share of the available fish. Hickling (1946) has estimated this increase by calculating the regression of rate of catch on fishing intensity over a period of years. This method has been followed for

the Australian data, and the line for the same years as in Fig. 2 is drawn in Fig. 3, demonstrating an average rise of 40 per cent. in rate of catch for every trawler-ton withdrawn from the fishery.

On the face of it, therefore, it would appear that this factor together with that of the retention of previously discarded fish species, would be adequate to account for the maximum rise of 50 per cent. in rate of catch during the war.

Obviously though, there must have been an increase in the size of the stocks of fish with the fall-off in fishing intensity, and that this indeed occurred is evident from the high rate of catch by the trawlers still holding in 1945-46 and 1946-47 when the fishing intensity had risen to about 80 and 130 per cent. of the pre-war level. The solution to the problem probably lies in the greater difficulty single or very few boats experience in finding concentrations of fish when working on their own, rather than when there is a fleet of, say, 12 vessels fitted with wireless inter-communication; it is on these concentrations (spawning or otherwise) that really payable trawling is dependent and though vessels of rival firms may not inform one another of good and bad fishing, the very presence of a trawler in any area is usually informative to any passing trawler. Such an effect would mask the real extent of the recovery in rate of catch. It must be concluded, therefore, that there has been a more or less sustained recovery by the fish stocks in the latter half of the war years, but that it is impossible from the available data to calculate the degree of this recovery.

From the biological point of view, the extent of the rest was adequate for recovery of the stocks. For two years the total catch was a sixth of the steady pre-war average, and for the two previous years had been two-thirds and less. The flathead (the chief species) begins to be caught at two and three years old, and the male spawns in the second summer after birth, and the female in the third; so that, even were the stocks of the early war years limited by a small spawning population (an extreme stage of overfishing for which there is no evidence in the present case) the recovering stocks of 1942-43 should have produced an increasingly large number of eggs, which would have produced catchable adults by 1945-46.

To assess the situation at the present day and to arrive at an estimate of a suitable intensity of fishing, it becomes necessary to examine the fishing intensity over the whole history of the fishery. As regards the trawlers, the use of the trawler-ton-month has already been justified as the most accurate available measure of fishing intensity, and the boat-month was used for the Danish seiners. These are two different units, and neither covers the full period. However, the number of trawlers operating in each year must be a fair measure of the fishing intensity over the years and if we can express the Danish seiners in similar units the two may be combined in the later years, and hence, the present situation compared broadly with that of any previous period. Some refinement can be achieved by using the trawler-ton rather than simply the numbers of trawlers, to allow for the larger, more efficient modern vessels. In comparing the efficiency of trawlers and Danish seiners, allowance must be made for the different time losses due to breakdowns, overhauls, &c. incurred by the two types of vessel.

An approach to this has been made and is set out in Table 5.

In this table the average annual catch for the trawlers for the past three years was obtained by excluding all vessels which entered or left the industry during the year for reasons other than overhaul, breakdown, &c. The same was done for the Danish seiners by selecting a number of vessels which seemed to be supplying returns regularly and were established in the industry; such a selection was necessary, as conditions have been very disturbed, with boats continually entering and leaving the fishery. In the event, most of the Danish seiners are represented by about 10 months' fishing, though some by as few as 7 in each year.

TABLE 5.—A COMPARISON OF THE AVERAGE EFFICIENCY OF DANISH SEINERS WITH TRAWLERS

(*Figures in brackets represent numbers of vessels from which the average was obtained*)

	Annual Catch by Trawlers per Trawler-Ton, M.S.B. Data	Average Annual Catch by Danish Seiners	Efficiency of Average Danish Seiner Expressed in Trawler-Tons
	lb.	lb.	
1944–45	4,725 (1)	167,500 (17)	36
1945–46	4,834 (4)	122,669 (20)	25
1946–47	4,008 (5)	114,631 (23)	29

It is natural that the figure for the Danish seiners' efficiency in trawler-tons (right-hand column of Table 5) should fluctuate somewhat, for the two types of vessel work rather different populations of fish, and (as has been shown elsewhere in this paper) the stocks of flathead worked by the Danish seiners have in the past two years shown a reduction to a degree which those worked by the trawlers have not. Obviously, therefore, this factor must be calculated anew each year till enough calculations have been made under stable conditions to strike an average. For the present we may reckon one Danish seiner equivalent to 30 trawler-tons, as a working approximation, remembering that this is probably an under-estimation, even for the years concerned, because of understatements in the Danish seiners' monthly returns. In Fig. 1 has been graphed the total fishing intensity of trawlers and Danish seiners expressed in trawler-tons. Where large numbers of trawlers were entering or leaving the fishery during a year the trawler-tonnage has been estimated by allowing half their true value to the incoming or outgoing vessels. The figures are set out in Table 6. It will be noted that it has been possible to calculate the fishing intensity on this basis for all the early years; these figures should not be taken as an exact measure of fishing intensity, for which the trawler-ton-month was used, but they do give a clear and reasonable picture covering the whole period of the fishery. The coincidence of high fishing intensity with low catch per unit effort and vice versa is apparent in the lower graph showing the catch per unit effort of the trawlers.

After considering oversea work of this nature, the fact which strikes one most forcibly about the course of the catch per unit effort, is the rise of only 50 per cent. during the wartime rest, and much of this rise can be accounted for by the reduction in size of the fleet and the retention of fish species previously discarded. As mentioned in the introduction, Hickling (1946) speaks of increases in the catch per unit effort of hundreds of per cent. in the case of the hake; the Report of the Ministry of Agriculture and Fisheries of Great Britain (1946) for 1939-44, on p. 23, gives the increases in trawl catch per unit effort in the North Sea as of the order of 300-400 per cent.; also for the west of Ireland and English Channel there are similar increases (though not in some other areas mentioned). As regards the First World War, Russell (1942) quotes figures showing an overall increase for the North Sea in catch per trawler day's absence of 100 per cent. between 1912-14 and 1919; and again, in the case of plaice and haddock on the Iceland grounds, the increases in catch per trawler day's absence are of several hundred per cent. It seems only reasonable, therefore, to assume from this that the east Australian trawl fish stocks were *not* heavily overfished before the war.

TABLE 6.—FISHING EFFORT BY TRAWLERS AND DANISH SEINERS

Year	Number of Trawlers	Trawler-Tons	Annual Trawler Catch in lb. per Trawler-Ton	Danish Seine Licences Issued	Estimated Monthly Average of Danish Seiners Working	Danish Seiners Expressed in Trawler-Tons	Total Fishing Effort in Trawler-Tons
1915–16 ..	3	660					
1916–17 ..	3	660					
1917–18 ..	3	660					
1918–19 ..	3	660					
1919–20 ..	4–7	1,104*					
1920–21 ..	7	1,549					
1921–22 ..	7	1,549					
1922–23 ..	7	1,549					
1924 ..	5	1,125	4,279				
1925 ..	5–8	1,455*	4,341				
1926 ..	9	2,052	4,124				
1927 ..	10	2,300	4,641				
1928 ..	10–16	3,000*					
1929 ..	17	4,001	3,672				
1930 ..	16	3,883	3,100				
1931 ..	16	3,883	2,944				
1932 ..	15	3,683	2,796				
1933 ..	14	3,443	2,781				
1934 ..	14	3,443	2,574				
1935 ..	13	3,243	3,013				
1936 ..	13	3,243	3,250				
1937–38 ..	14	3,567	3,170	5	...	150†	3,617
1938–39 ..	14	3,567	3,182	6	..	180†	3,747
1939–40 ..	14–7	2,740*	..	10	..	300†	3,040
1940–41 ..	4	949	4,064	26	..	780†	1,729
1941–42 ..	3	662	3,202	49	..	1,470†	2,132
1942–43 ..	1	237	4,772	19	4	120	357
1943–44 ..	1	237	3,810	60	10	300	537
1944–45 ..	1–4	635*	4,406	97	36	1,080	1,715
1945–46 ..	4	1,033	5,243	105	57	1,710	2,743
1946–47 ..	6–11	2,515*	3,603	123	67	2,010	4,525

* Approximated figures.

† Overestimate because of lack of knowledge on number of Danish seiners actually working.

But if we follow the history of the trawl fishery since 1924, it becomes quite evident that there was over at least one period a greater fishing intensity being exerted than the stocks could continue to stand. In 1929 the total catch and the fishing intensity were at a maximum, but not the rate of catch, which had already begun to decline. Moreover, the rate of catch continued to decline after 1929 in spite of a declining fishing intensity, until about 1934-35, when, with 12 or 13 trawlers of a total tonnage of 3,250 to 3,500 tons and a total catch of 10–12 million lb., a stable situation seems to have been reached. Even so, it should be noted that the rate of catch showed no tendency to rise, for in 1937-38 and 1938-39 it was lower still. If now, we suppose that this level of fishing intensity was higher than the stocks could sustain there would have been a continued fall in the rate of catch, but this was not so, or not marked; contrariwise, if the intensity was less than the stocks could sustain, the rate of catch would surely over the 5 or 6 years to 1939 have begun to improve, but this was certainly not the case. Yet as soon as the burden of fishing began to relax, the rate of catch did improve.

It seems that we have here what may be called an empirical optimum catch (12 million lb. per year) which, under present conditions, may be taken by a total fishing effort equivalent to 3,250—3,500 trawler-tons. It is not suggested that this is the true optimum catch, for that involves the size (weight) at which the fish are best taken; but since it would be a matter of a decade at the very least before such an estimate could in practice be made, the present figure is put forward as a practical guide to what the east Australian trawl-fish stocks will stand under present fishing methods. Within a few years' time biological research may demonstrate, for example, that the use of a larger mesh in the cod-end would be of advantage to the industry by sparing the two-year fish for a further year's growth, or that partial closure of some grounds (particularly the Botany ground) would inincrease the population potential; if such recommendations were made and implemented and did prove advantageous, the effect would be seen in a rise in the rate of catch. Such a rise would mean a rise also in the total catch, and if big enough, an increase of the fishing intensity might then be warranted. But under the present conditions of no restriction on the cod-end mesh (in practice the 3 in. mesh is generally used) or on the areas or seasons in which fishing is done, this empirical optimum can be put forward with some confidence.

Turning now to the situation in 1946-47, we see from Fig. 1 that the fishing intensity has so far overreached this empirical optimum that it is in fact greater than at any time in the history of the fishery, 1929 not excepted, even though the efficiency in trawler-tons of the Danish seine fleet is probably under-estimated. The total catch certainly is not as high as 1929, but there is reason to believe this figure also an under-estimation and there has undoubtedly been a comparative failure of the flathead (see next section). There is some evidence already that the catch is below the economic level of the fishery, for Danish seiners have been leaving the industry over the last twelve months and there is at the time of writing, a tie-up of the trawlers and most of the Danish seiners, for which one of the reasons is an unusual shortage of fish.

Quite evidently, if the 1946-47 fishing intensity continues (it is actually increasing), there will be a repetition of the recession after 1929, when the catch fell to 10 million lb. in 1933 and for six years the numbers in the trawler fleet continued to diminish, partly as a result of economic stress.

The problem, therefore, is to find means of reducing the fishing effort towards the 1932-1937 level of intensity of about 3,250–3,500 trawler-tons. This means a reduction from the 1946-47 level by 1,000 trawler-tons, or their equivalent in Danish seiners, that is, a reduction of the order of 4 trawlers or 33 Danish seiners. At present we have little scientific reason for preferring the trawler over the Danish seiner, save that the trawler tends to catch a somewhat larger run of fish. But it is a matter of common sense that the greater part of the fishing potential should be provided by the trawlers, since they work deeper water (an average of 60–65 fathoms), and distant grounds, which are more or less useless to the Danish seiner, save as reservoirs of stock from which fish may move into their main zones of operations. Beyond these observations, it is at present outside the range of the fishery biologist's special knowledge to determine the desirable proportion of trawlers to Danish seiners.

But that the numbers of both types of vessels should, in their own interests, be reduced to a total fishing potential in the region of 3,250–3,500 trawler-tons, cannot be too strongly urged. Moreover, now is the time to do it—before even more vessels enter the industry*; a trawler to-day is worth something like £40,000 when new, and a Danish seiner perhaps £6,000–£12,000, so that any reduction of the fleet would involve considerable capital equipment. In more ways than one, prevention is better than cure. Whatever research may show concerning mesh restrictions and closure of grounds, we know enough now to say that the fixing of the level of fishing intensity will outweigh in importance all other conservational measures.

9. The Catch of Flathead

It is a coincidence that the post-war recovery in this fishery has been complicated by what is possibly an adverse natural fluctuation of the flathead, so that the 1946-47 decline in catch per unit effort cannot be undeniably (or wholly) laid at the door of the increased fishing effort. The arguments which will be put forward in this section are of a somewhat general nature, but appear to offer at least a partial explanation of the recent fall in the catch of flathead per unit fishing effort, and it was thought advisable to include the section, as the effects of this fluctuation are liable to cause confusion, particularly at the time of writing, when the questions of recovery and overfishing are being discussed. This section is therefore in the nature of an appendix to the rest of the paper.

As previously mentioned, the flathead (*Neoplatycephalus macrodon*) is the most important species of the eastern Australian trawl fishery, accounting for slightly more than half the catch of the trawlers and

* The figure given for the fishing intensity in 1946-47 was based on 9 or 10 trawlers, yet at the time of writing there are already 13 trawlers working.

a greater (but variable) proportion of the Danish seiners' catch; indeed, the geographical limits of the trawl fishery agree very well with those of the flathead.

Apart from the records in Tables 2 and 3, our information on the catch of flathead begins in 1943-44, when both Danish seiners and trawlers were supplying monthly returns which detailed the catch by species.

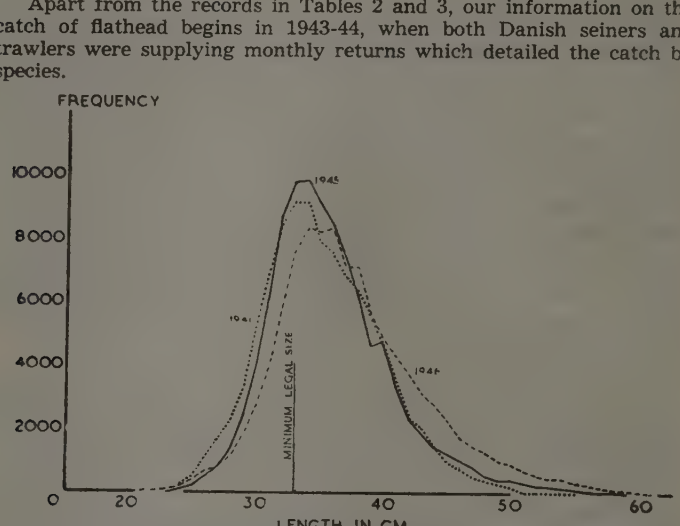

FIG. 4.—*Flathead length-frequency polygons for May to December* – Dotted line: 1941, all boats. Continuous line: 1945, Danish seiners only. Dashed line: 1946, Danish seiners only.

From May to December 1941, a full-scale sampling programme on the flathead was being prosecuted in the Sydney Metropolitan Fish Markets, where all the trawled fish are sold. This programme was discontinued during the war with Japan, and resumed in 1945. From this work the length-frequency polygons in Fig. 4 have been constructed to compare the relative numbers of large and small flathead taken in 1941, 1945, and 1946. Since only the months of May-December were available for 1941, only these months have been used in the other years. The total catch from all types of vessel was used first, but when the 1946 fish proved to be larger than those of 1945, it was thought that this might be a reflection of the greater use of trawlers in 1946, and so these years were compared on the basis of the Danish seiners' catch alone. Unfortunately, the 1941 data could not be similarly dissected, and the gross catch was used; in the event, it appears that the 1941 fish were the smallest of them all, and this tendency could only have been increased by using the Danish seiners' catch alone.

The figures are based on a total of 4,000–5-000 measurements in each month, with the exception of May and June, when usually so few flathead reach the market that the measurer is unable to maintain his quota. The total catch for each month is known, and a factor was worked out by which the market length-frequency figures in each

month were multiplied, to bring them to the approximately correct proportion of the total catch for the months May–December for that year. For ease of comparison the three polygons have been drawn to about the same height, though the actual weights of fish caught were very different in the three years.

A number of features stand out clearly from such a comparison. The modes of the 1941 and 1945 polygons fall very close together, and the 1946 mode at a point 2 cm. larger. Again, there is in 1941 a sudden drop away in numbers after 50 cm. as compared with the other two years, and a considerably greater proportion of small to large fish in 1941 than 1945, and in 1945 than 1946, the actual percentage by numbers of fish below legal size in the three years being 39, 35, and 25. These three features of the 1941 polygon are regular and expected symptoms of an exploited fishery as compared with virgin stock, or one less fully exploited. (It must not be overlooked that there had been considerably reduced fishing for 2 years prior to 1941, with presumably an increase in the proportion of larger fish.) The features of the 1946 polygon, on the other hand, are in all respects the opposite of 1941, large fish up to the very largest sizes being in much greater proportion than small, compared with 1945. And yet, not only had there been a doubling of the effort by Danish seiners in 1946, but a decrease in catch per unit of effort. The 1945 stock was rested or quasi-virgin and its reaction to renewed fishing under normal conditions would have been a reduction of the proportion of large fish and an increase in the proportion of small; and yet the opposite took place.

One can only conclude either that 1945 saw an extremely prolific brood of fish of about 33 and 34 cm.—so prolific that they reduced the proportion of old accumulated stock in the catch to approximately that of 1941; or, as seems more likely in view of the fall in catch of flathead per trawler-ton by the trawlers, there was a "failure" in 1946 of the small fish of about 30–33 cm. (i.e. those spawned in the summer of 1943-44), as a consequence of which, the increasing fishing effort bore relatively more heavily on the older, sparser year groups with a resultant increase in the proportion of them in the catch.

That the latter is the more likely alternative can hardly be doubted after examining Table 4, where the flathead stocks, as revealed by the trawlers' catch per unit effort, are seen to fall nearly 50 per cent. over the last two years, and in the case of the Danish seiners is only 1/11th of 1944-45 and 1/6th of 1945-46 in spite of a rise in the rate of catch of other species. Understatements of their catches by the Danish seine boat owners could hardly account for such a fall in rate of catch, and it must be taken as reflecting some very big change in the flathead population.

10. Acknowledgments

The writer wishes to acknowledge the help of the officers of the New South Wales State Fisheries Department and of the Maritime Services Board in supplying most of the statistical material on which this paper is based, and also that of the managers of Cam & Sons Pty. Ltd., and Red Funnel Trawlers Pty. Ltd., for the opportunity to sight some of the old log sheets from their vessels. Mr. John Woore, market

measurer of the State Fisheries Department, made the many thousands of measurements on which the last section of the paper is based. The writer's thanks are due also to M. Blackburn of this Division and particularly to G. L. Kesteven, now with the Food and Agriculture Organization of the United Nations, both of whom did some of the preliminary assembling of the statistical material. The figures were prepared by K. Wilson of this Division.

11. References

Colefax, A. N. (1934).—A preliminary investigation of the natural history of the tiger flathead (*Neoplatycephalus macrodon*) on the South-Eastern Australian coast. I. *Proc. Linn. Soc. N.S.W.* 59: 71-91.

Graham, M. (1939).—The sigmoid curve and the overfishing problem. *Rapp. Cons. Explor. Mer,* Vol. 110, No. 2.

Great Britain, Ministry of Agriculture and Fisheries (1946).—Fisheries in war-time. Report on the sea fisheries of England and Wales for the years 1939-1944 inclusive.

Herlihy, F. J. (1927).—The New South Wales State trawling enterprise: historical record, 1915-1924; confidential report to the New South Wales Government.

Hickling, C. F. (1931).—A comparison of the Vigneron-Dahl trawling gear with the steam otter trawl, in the hake fishery. *J. Cons. Int. Explor. Mer* 6: 421-31.

———— (1946).—The recovery of a deep sea fishery. Gr. Brit., Min. Agric. Fish., *Fish Invest.* (Ser. 2) Vol. 17, No. 1.

Lundbeck, J. (n.d.).—The principles relating to the statistics of yield in deep sea fishing. Gr. Brit., Min. Agric. Fish. Translations from Foreign Publications No. 324. (It is not possible to give the date, reference or German title of this paper, as the records of these translations have apparently been destroyed.)

Russell, E. S. (1942).—"The Overfishing Problem." (Cambridge Univ. Press.)

Some Studies in the Growth of Tomato Plants and Comparison of Tomato Varieties Grown under Irrigation

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Summary

Tomato varieties were studied for three seasons at Red Cliffs, in the Murray Valley, and at Griffith, in the Murrumbidgee Irrigation Area. They were also grown and studied at Katherine, in the Northern Territory in the winter of 1945.

In all, 36 varieties were included in these studies. In the final (1945-1946) season, the twelve most promising varieties were grown, and detailed studies were made of their plant structure and fruit characters.

No one variety had all the qualities favoured by growers and consumers, but parent material is available for the production by plant breeding of a variety of good bush type, producing a high yield of good quality, medium sized fruit when grown under unstaked cultural conditions and watered by furrow irrigation.

Pearson (various strains) yielded well in a number of field trials. H.E.S. 927M, Riverside, Pearson 29-17, Grosse Lisse, and Break O'Day had fruit of satisfactory size and shape, whilst Red Cloud, Break O'Day, and Stemless Pennred showed very good fruit colour. Morse's Special Early, Red Cloud, Pearson 29-17, and H.E.S. 927M had good internal fruit characters although the pink colour of H.E.S. 927M rendered it commercially unsuitable. Adelaide Dwarf Red, Tatura Dwarf Globe, H.E.S. 927M, and Pearson 29-17 had satisfactory types of bush. Garden State, Bounty, Tatura Dwarf Globe, and the so-called Chinese types were among the earliest varieties.

Until more suitable varieties are available, Pearson 29-17 appears to be one of the most desirable ones to grow under the conditions stated. It has yielded well in a number of experimental and commercial trials and has produced fruit of comparatively good quality, suitable for both canning and the fresh market. The bush type is very satisfactory, and provides good cover for the fruit. It is a mid-season to late variety.

1. Introduction

An expansion of the area under tomatoes in the major irrigation areas of Australia took place during the war years, so the growing of tomatoes for canning and processing is now a well-established industry in the Murrumbidgee Irrigation Area of New South Wales, and the Goulburn Valley in Victoria. Variety trials were conducted at Red Cliffs in the Murray Valley, and at Griffith in the Murrumbidgee Irrigation Area, during the three seasons 1943-1944, 1944-1945, and 1945-1946. The object was to determine varieties suited to conditions in these districts. Each year unsatisfactory varieties were discarded and new varieties introduced. Thus the list of varieties differs between centres and between seasons, although a few of the popular commercial varieties were included in all trials. In the 1945-1946 season the work at both centres was confined to the twelve varieties chosen as most likely to be suitable for irrigation conditions. Growth studies, as detailed as possible, were made with the staff available. Unfortunately,

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the plants at Griffith were, in this season, severely attacked by spotted wilt which deformed the plants, reduced the yield and lowered the quality of the fruit.

In the winter of 1945 a trial was conducted at the Australian Army Farm, Katherine, Northern Territory, by Lieut. H. Scott-Young.

Growth conditions differed widely between the various centres. At Red Cliffs, the tomatoes were planted at a standard spacing of 5 feet by 3 feet during the 1943-1944 and 1944-1945 seasons, and at 4 feet by 3 feet during the 1945-1946 season. They were grown on a deep sandy loam, classified as Barmera sand by Hubble and Crocker (1941), and were watered by furrow irrigation.

At Griffith, the soil was a brown clay loam overlying a heavier subsoil at a few inches and was of the type classified as Beelbangera clay loam by Taylor and Hooper (1938). The land had been graded so as to have an even slope of the order of 1 inch per chain. The tomatoes were spaced 2½ feet apart in rows 4 feet apart and were watered by furrow irrigation.

At Katherine, the tomatoes were grown as a winter crop and were spaced 2½ feet apart in rows 4 feet apart.

2. Results

(*a*) *Yield of Fruit*

Yielding ability is one of the factors which determine the commercial suitability of a variety to any environment. Other important factors include disease resistance, bush type, and fruit quality. The fruit yields of the different varieties are shown in Table 1.

The most noticeable feature of Table 1 is the scarcity of varieties that yield well under all the environments included. The inconsistency was due, in part, to the high incidence of disease in some of the trials. The varietal yields at Red Cliffs in the 1943-1944 and 1945-1946 seasons were considerably reduced by the presence of Fusarium wilt. The 1945-1946 yields at Griffith are a measure of the ability of the varieties to produce fruit when infected with spotted wilt. In this season, the three highest yielders at Griffith were early varieties with a small compact bush habit, namely, Tatura Dwarf Globe, Adelaide Dwarf Red, and H.E.S. 927M. The symptoms of both Fusarium wilt and spotted wilt are clearly described by Doolittle (1943). Norris (1947) describes the variations in symptoms of spotted wilt.

Varieties that yielded well in the early trials but were excluded because of unsatisfactory bush habit or fruit type were Santa Clara Canner, Bonnimar, and San Marzano. The other strains of Pearson were discarded in the final year in favour of Pearson 29-17.

Varieties that yielded well over a wide range of conditions were Pearson (various strains) and Riverside. H.E.S. 927M, a variety with pink fruit, and Red Cloud yielded fairly well at both Red Cliffs and Griffith in the 1945-1946 season—the only year in which they were included. Adelaide Dwarf Red, Tatura Dwarf Globe, Bonnimar, and Morse's Special Early yielded well in isolated trials.

In the trial at Katherine, Pearson 29-17 and Garden State were the heaviest producers, yielding 27 and 24 tons per acre respectively.

TABLE 1.—YIELDS OF TOMATO VARIETIES GROWN UNDER IRRIGATION

Variety	Total Yield (tons per acre)						
	Red Cliffs			Griffith			Katherine
	1943–1944	1944–1945	1945–1946	1943–1944	1944–1945	1945–1946	1945 Mean
Adelaide Dwarf Red	..	26·3	12·6	..	..	11·2	..
Bonnimar	..	21·4	..	29·9	13·4	..	..
Bonny Best	8·6	..	..	..	14·0	..	21·1
Bounty	..	..	..	..	12·4	..	..
Break O'Day	..	..	16·0	..	..	8·3	..
Essar	..	..	..	18·9	..	..	..
Garden State	..	..	10·6	..	..	7·2	24·2
Greater Baltimore	..	..	..	20·5	..	..	..
Grosse Lisse	..	22·3	16·7	14·4	12·7	9·4	18·8
H.E.S. 927M	..	..	15·6	..	..	10·4	..
Indiana Baltimore	11·0	23·0	15·2	23·3	14·2	8·4	..
Marglobe	9·5	..	..	20·9	..	..	19·8
Morse's Special Early	..	27·0	13·0	..	..	7·7	..
Norton	..	..	..	24·1	15·8	..	..
Pan America	10·9	18·9	..	20·7	15·5	..	..
Pearson	..	25·3	..	26·5	18·8	..	22·3
Pearson 29–17	15·0	26·4	19·7	..	18·4	9·3	26·7
Pearson 32–5	11·8	..	..	..	19·0	..	..
Pennheart	..	21·8	..	..	12·2	..	..
Pritchard	10·6	..	..	..	..	..	..
Red Cloud	..	..	19·8	..	..	9·7	..
Red Marhio	..	..	..	..	..	..	18·5
Riverside	13·8	..	19·3	24·2	16·6	8·5	..
Rouge de Marmande	10·0	..	..	..	..	..	..
Rutgers	..	21·4	..	19·1	14·2	..	20·8
Santa Clara Canner	10·3	..	..	26·1	..	..	..
San Marzano	..	..	..	26·9	..	..	..
San Marzano Selection	..	..	..	33·0	15·9	..	..
Sioux	..	..	..	..	..	..	22·6
Stemless Pennorange	..	..	..	..	10·0	..	..
Stemless Pennred	..	24·0	16·1	..	15·3	7·6	..
Stokesdale	10·7	..	..	24·1	14·3	..	..
Tatinter	..	..	..	..	15·0	..	21·5
Tatura Dwarf Globe	7·1	..	12·1	19·8	14·8	12·5	20·4
Wasatch Beauty	..	19·2	..	..	14·1	..	..
Washstate	..	..	..	..	12·3	..	20·8
Significant difference at 5%	3·57	5·40	2·67* 2·77† 2·95‡ 3·07§ 3·24‖	4·10	3·31	1·89	Individual plot yields not available
Significant difference at 1%	4·77	7·30	3·55* 3·69† 3·92‡ 4·16§ 4·31‖	5·40	4·40	2·60	..

* For comparisons among varieties other than Grosse Lisse, Indiana Baltimore and Stemless Pennred
† For comparison of other varieties with Grosse Lisse
‡ For comparison of other varieties with Indiana Baltimore or Stemless Pennred
§ For comparison of Grosse Lisse with Indiana Baltimore or Stemless Pennred
‖ For comparison of Indiana Baltimore with Stemless Pennred

(b) Maturity

There is a consumers' demand for fresh tomatoes early in the season. In addition, the canneries are seeking early fruit in order to extend their period of processing. Hence, the production of fruit early in the season is a desirable feature. The mean maturity period of each variety was determined by calculating a weighted mean number of days from transplanting to harvesting. (See Appendix 1 for method.) These mean maturity periods are shown in Table 2.

TABLE 2.—MEAN NUMBER OF DAYS FROM TRANSPLANTING TO PICKING OF TOMATO VARIETIES GROWN UNDER IRRIGATION

Variety	Red Cliffs			Griffith		
	1943–1944	1944–1945	1945–1946	1943–1944	1944–1945	1945–1946
Adelaide Dwarf Red	..	121	105	..	..	121
Bonnimar	..	131	..	132	143	..
Bonny Best	110	..	..	..	135	..
Bounty	..	..	..	..	124	..
Break O'Day	..	..	113	..	..	135
Essar	..	..	..	137	..	..
Garden State	..	..	114	..	..	114
Greater Baltimore	..	..	..	123	..	..
Grosse Lisse	..	134	112	127	142	134
H.E.S. 927M	..	..	107	..	..	128
Indiana Baltimore	114	129	126	126	141	132
Marglobe	117	..	..	131	..	..
Morse's Special Early	..	124	108	..	..	128
Norton	..	..	..	126	143	..
Pan America	116	138	..	125	141	..
Pearson	..	132	..	127	142	..
Pearson 29–17	122	132	118	..	142	137
Pearson 32–5	124	..	..	..	146	..
Pennheart	..	121	..	..	127	..
Pritchard	111	..	..	..	..	..
Red Cloud	..	..	109	..	..	130
Riverside	119	..	114	129	145	136
Rouge de Marmande	112	..	..	..	..	..
Rutgers	..	131	..	133	145	..
Santa Clara Canner	119	..	..	135	..	..
San Marzano	..	..	..	135	..	..
San Marzano Selection	..	..	..	132	145	..
Stemless Pennorange	..	..	..	..	144	..
Stemless Pennred	..	133	113	..	145	135
Stokesdale	113	..	..	126	138	..
Tatinter	..	..	..	..	138	..
Tatura Dwarf Globe	108	..	107	116	133	126
Wasatch Beauty	..	124	..	..	132	..
Washstate	..	..	..	..	136	..

The 1943-1944 season was the earliest and the 1944-1945 season was the latest at both Red Cliffs and Griffith. Garden State had the lowest mean maturity period of any variety at Griffith being a week earlier than Adelaide Dwarf Red by this method whilst at Red Cliffs it was nine days later. Although Adelaide Dwarf Red, and Tatura Dwarf Globe produced more fruit at the beginning of the season than did Garden State, but continued to produce fruit later in the season, Garden State tended to produce its fruit in a batch in the mid-season

period and the low figure for maturity time of this variety is due to a rapid falling off in yield towards the end of the season rather than to the production of fruit early in the season. Other early varieties were Adelaide Dwarf Red, Tatura Dwarf Globe, H.E.S. 927M, Bounty, Rouge de Marmande, Bonny Best, Morse's Special Early, and Red Cloud. Pearson, Rutgers, Pan America, and San Marzano were among the latest varieties.

(*c*) *Fruit Characters*

For canning and fresh market purposes a smooth bright-red globular fruit is desired. It should be free of blemishes such as cracking of the skin surface or a deep stylar and scar. A strong skin and a large number of small internal fruit cells are features which make the fruit easier to transport. A large fibrous core extending inward from the stem junction is not desirable. A high proportion of the fruits should be between 1½ and 2½ inches in diameter as large fruit cannot be packed whole into normal sized cans. For pulping and sauce manufacture, the shape and freedom from surface blemishes is not important. A large proportion of pulp with a high percentage of total solids is required.

Observations of fruit characters, some measurements of fruit size, and keeping quality were made in the early years. It was, however, only in the last year that a uniform rating system was adopted at Red Cliffs and at Griffith. Fifteen points were allotted for external fruit characters, fifteen points for internal fruit characters, and fifteen points for canning quality.* The ratings awarded the varieties are shown in Table 3.

For the fruit studies at Griffith, fruit was taken from bushes without any symptoms of spotted wilt. It was, however, impossible to get sufficient fruit for canning tests from disease-free plants, so samples for this purpose were obtained from the entire area of each variety.

At both centres, the variety Adelaide Dwarf Red was entirely unsatisfactory because of its irregular shape, and Garden State because of its tendency to split. No variety was given full points for shape and freedom from splitting. Varieties of a satisfactory size were H.E.S. 927M, Riverside, and Pearson 29-17, whilst Break O'Day, Stemless Pennred, and Red Cloud had the best colour. Garden State had a low ratio of seeds to flesh and a good arrangement of fruit cells and cell walls, but the flesh texture was rather coarse. Morse's Special Early, Red Cloud, Pearson 29-17, H.E.S. 927M, Riverside, and Break O'Day had internal characters that were satisfactory.

Typical fruit of four varieties are shown in Plate 1. Adelaide Dwarf Red (No. 1 in Plate) shows the irregular fruit of the so-called Chinese type, with a large number of small fruit-cells clustered around the edge of the fruit. Tatura Dwarf Globe (No. 2 in Plate) shows a small number of large pulp-cells, with thin walls between them. This type of fruit is easily damaged during transport. H.E.S. 927M

* Samples of each variety were canned by Mr. R. S. Mitchell of the Division of Food Preservation at the Griffith Co-operative Cannery and at the factory of the Mildura Co-operative Fruit Company.

TABLE 3.—FRUIT CHARACTERS OF TOMATO VARIETIES GROWN UNDER IRRIGATION AT RED CLIFFS AND GRIFFITH, 1945-1946 SEASON

Variety	Rating of Red Cliffs Fruit—										Rating of Griffith Fruit—										Number of Cells per Fruit (Mode)	
	External Characters				Internal Characters						External Characters				Internal Characters							
	Shape and Freedom from Cracking (0–5)	Size and Uniformity (0–5)	Colour (0–5)	Total (0–15)	Ratio Seed Flesh (0–5)	Texture (0–5)	Cells and Cell Walls (0–5)	Total (0–15)	Canning Quality (0–15)	Total Fruit Rating (0–45)	Shape and Freedom from Cracking (0–5)	Size and Uniformity (0–5)	Colour (0–5)	Total (0–15)	Ratio Seed Flesh (0–5)	Texture (0–5)	Cells and Cell Walls (0–5)	Total (0–15)	Canning Quality (0–15)	Total Fruit Rating (0–45)	Red Cliffs	Griffith
Adelaide Dwarf Red ..	1	1	1	3	1	2½	1½	5	4	12	1	4	3	8	3	2	3	8	8	24	8	10
Break O'Day..	4	3	1	8	3	3	4	10	12½	30½	4	3	5	12	4	4	3	11	9	32	5	4
Garden State..	2½	2½	1½	6½	3½	3½	3	10	12½	29	2	3	3	8	5	2	5	12	8½	28½	6	8
Grosse Lisse ..	4	3	4	11	3	2½	2½	8	10½	29½	4	4	4	12	3	4	3	10	9½	31½	5	4
H.E.S. 927M ..	3	3	2	8	3	2	3½	8½	10½	27	3	5	3	11	4	4	4	12	8½	31½	5	5
Indiana Baltimore ..	3	1½	2½	7	4	2½	2½	9	11½	27½	3	4	4	11	3	4	4	11	7½	29½	6	6
Morse's Special Early ..	2	2	2	6	4	4½	4½	13	11	30	3	4	4	11	4	4	5	13	..	..	8	9
Pearson 29–17	4	3	4	11	3	3½	2½	9	13	33	3	5	4	12	3	4	5	12	8	32	6	6
Red Cloud ..	2	3½	3	8½	3	3½	3½	10	10½	29	4	3	5	12	4	4	5	13	8	33	8	8
Riverside ..	2	3	2½	7½	3½	4	3½	11	12	30½	4	5	4	13	3	3	4	10	10	33	6	5
Stemless Pennred ..	3	2	3	8	1½	1	4	6½	11½	26	3	4	5	12	3	4	4	11	8½	31½	5	5
Tatura Dwarf Globe ..	3	3	1	7	2	2	2	6	10½	23½	3	4	3	10	3	4	3	10	9½	29½	6	5

(No. 12 in Plate) shows the smooth globular fruit with a large number of small pulp-cells with firm divisions between them, distributed throughout the entire fruit. The lighter colour of the fruit of this variety can also be seen. In arrangement of pulp-cells, Pearson 29-17 (No. 4 in Plate) is intermediate between Tatura Dwarf Globe and H.E.S. 927M.

Pearson 29-17, Washstate, Garden State, and Red Marhio varieties produced the best quality fruit at Katherine.

(d) Keeping Quality

During the 1943–1944, and 1944–1945 seasons at Red Cliffs, and during the 1945–1946 season at Griffith, one hundred ripe fruits of each variety were packed in a box and were examined daily, the unsound fruit being counted and removed at each examination. From the data obtained, graphs were made of the percentages of sound fruit remaining after various time-intervals and the varieties were graded into three classes: (i) good-keeping quality, (ii) medium-keeping quality, (iii) poor-keeping quality.

The gradings on this basis are shown in Table 4.

TABLE 4.—TOMATO VARIETIES GROUPED ACCORDING TO KEEPING QUALITY

——	Good Keeping Quality	Medium Keeping Quality	Poor Keeping Quality
Red Cliffs 1943–1944 ..	Indiana Baltimore Pearson 29–17 Pearson 32–5 Riverside	Bonny Best Pan America Pritchard Rouge de Marmande Santa Clara Canner Stokesdale	Marglobe Tatura Dwarf Globe
Red Cliffs 1944–1945 ..	Bonnimar Wasatch Beauty	Indiana Baltimore Morse's Special Early Pearson 29–17 Pennheart Stemless Pennred Pearson	Adelaide Dwarf Red Early Rutgers Grosse Lisse Pan America
Griffith 1945–46 ..	Adelaide Dwarf Red Pearson 29–17 Tatura Dwarf Globe	Break O'Day Grosse Lisse H.E.S. 927M Indiana Baltimore Stemless Pennred	Garden State Morse's Special Early Red Cloud Riverside

Although the test was on too small a scale to draw conclusive results, tomatoes of the Pearson type were consistently classed as being of good keeping quality.

The differences in keeping qualities as shown by storage times were slight. For example, in the 1943–1944 test half of the fruit of Tatura Dwarf Globe became unsound in 8 days, whereas it was only 11 days before the same proportion of the fruit of Pearson 29–17 was unsound. The differences between the good and bad keepers were of the same order in the succeeding years.

(*e*) *Structure of Plant*

Comparisons between bush structures of the varieties were made at Red Cliffs and Griffith during the 1945–1946 season. Twelve plants of each variety were measured at Red Cliffs and sixteen at Griffith. The lengths of the basal internodes were measured when they had finished elongating. The leaves were counted, and the heights of the plants were measured at fortnighly (Red Cliffs) or monthly (Griffith) intervals throughout the growing season. In addition, the plants were rated for the general appearance of the bush on a scale of 1 to 10, the rating increasing with the suitability of the bush for unstaked and unpruned culture. The ideal bush is small, erect and compact, bearing fruit in such a position as to be held off the ground and shaded by the foliage. Such a bush would be rated at 10.

The comparison between plant structures of the varieties is shown in Table 5.

The basal internodes reached a greater length on a sandy soil at Red Cliffs than on a clay loam at Griffith. Adelaide Dwarf Red and Tatura Dwarf Globe were the varieties with shortest internodes.

Varieties with compact bushes were Adelaide Dwarf Red, Tatura Dwarf Globe, H.E.S. 927M, and Pearson 29–17. Morse's Special Early had long straggling branches which were frequently damaged by cultivating implements and which left the fruit exposed to the sun and in contact with the soil. Riverside was satisfactory at Red Cliffs, but the bushes were brittle at Griffth where they split apart at the junctions of the main stems, allowing the branches to sag to the ground and form roots at the nodes whilst exposing the fruit to the sun.

At Red Cliffs, the heights of the plants were measured until the plants became decumbent. Of the dwarf varieties, H.E.S. 927M was slightly taller than Adelaide Dwarf Red and Tatura Dwarf Globe. Garden State and Pearson 29–17 were somewhat the least decumbent of the other varieties.

Except for Morse's Special Early at Griffith, the varieties showed very little difference in the number of main branches on each bush, although Indiana Baltimore, Morse's Special Early, Grosse Lisse, and Stemless Pennred developed them later than the other varieties. At Griffith, Morse's Special Early had fewer branches and these were more straggly than those of the other varieties. In addition to the various features of bush habit, the number and the relative size of the leaves were determined. A typical leaf of each variety for a photographic illustration was selected by removing 51 mature leaves at random, arranging them in order of their length from point to stem end of petiole, and taking the 26th leaf. If this leaf was abnormal in any other character it was discarded

TABLE 5.—COMPARATIVE STUDIES IN PLANT STRUCTURE OF TOMATO VARIETIES AT RED CLIFFS AND AT GRIFFITH, 1945–46 SEASON.

Variety	Red Cliffs										Griffith							Area of Typical Leaf (Lamina only included) (sq. in.)
	Average Length of Five Basal Internodes (in.)	Average Height of Plants (inches)				Average Number of Leaves per Plant				Average Number of Main Shoots per Plant 9.1.46	Rating for Bush Type (max. = 10)	Average Length of Five Basal Internodes (in.)	Average Height of Plants at Transplanting (in.)	Average Number of Leaves per Plant			Average Number of Main Shoots per Plant		Rating for Bush Type (max. = 10)	
		8.xii.45	13.xii.45	29.xii.45	22.i.46	6.xii.45	13.xii.45	27.xii.45	14.i.46					20.xii.45	18.i.46	16.ii.46	19.xii.45	25.v.46		Griffith
Adelaide Dwarf Red ..	1·89	4·7	7·2	11·9	18·6	11·7	28·9	104·0	224·5	4·2	6	0·39	7·1	33·1	163·8	508·8	6·7	11·3	7	3·0
Break O'Day	2·44	7·5	10·9	18·3	30·5	9·9	22·0	65·2	193·7	4·3	4	0·78	8·8	21·6	93·6	358·0	5·0	12·8	5	6·0
Garden State	2·92	6·2	8·6	14·9	23·1	9·8	19·3	47·0	121·3	3·9	6	0·64	9·0	22·8	83·4	247·3	5·7	13·8	5	7·4
Grosse Lisse	2·49	6·0	8·7	15·5	30·8	10·7	21·4	64·2	161·9	4·6	6	0·56	5·5	13·7	70·9	241·9	3·5	12·3	4	5·2
H.E.S. 927M	2·47	5·7	8·8	12·3	21·3	9·7	21·4	67·1	160·0	4·5	7	0·64	7·6	23·1	129·7	368·8	5·3	11·8	9	9·6
Indiana Baltimore ..	2·14	7·1	10·4	18·6	31·5	13·5	25·8	77·2	186·7	4·3	6	0·59	7·0	16·6	77·8	289·2	1·6	12·5	4	6·8
Morse's Special Early ..	2·22	6·6	10·5	17·2	27·9	12·9	32·8	100·1	230·6	4·5	4	0·60	10·5	33·6	143·1	565·6	1·6	9·9	3	6·4
Pearson 29–17	2·89	6·3	9·3	16·3	26·0	10·1	22·1	67·4	168·3	4·0	8	0·73	9·5	25·7	101·4	341·6	5·9	13·4	7	7·0
Red Cloud	2·45	7·3	9·3	16·9	29·2	11·7	25·7	84·8	210·7	4·1	4	0·69	9·7	25·4	141·1	450·2	5·8	11·8	5	6·4
Riverside	2·55	7·8	10·8	18·7	27·7	12·5	24·5	72·3	201·2	4·4	8	0·74	9·5	23·3	114·9	410·3	5·9	14·5	3	10·0
Stemless Pennred ..	2·15	5·7	8·2	15·6	27·3	11·2	21·2	56·1	139·8	4·2	6	0·67	5·1	15·1	84·6	304·8	3·9	11·9	2	6·4
Tatura Dwarf Globe ..	1·84	3·8	6·0	10·7	17·6	10·5	22·4	83·5	198·7	5·1	7	0·38	5·5	29·1	152·1	465·4	5·9	11·1	7	3·0

Heights of plants in the field were not measured at Griffith because most of the varieties showed a tendency for the bushes to split during cultivation operations.

and another leaf was selected by repeating the same process. This leaf was photographed against a background of graph paper on which the one-inch squares had had their outlines darkened with indian ink (Plate 2).

The relative leaf areas of the varieties were estimated as follows:—The outlines of the 24th, 25th, 26th, 27th and 28th leaves at Griffith were traced and the areas of leaf blades were measured with a planimeter. The average area of these five median leaves was calculated. This figure was multiplied by the number of leaves shown in Table 5 to give the relative leaf areas of the varieties. The absolute areas could not be determined as there was always a large number of partly grown leaves on the bushes.

The relative leaf areas of the varieties at monthly intervals during the growing season at Griffith are shown in Table 6.

TABLE 6.—RELATIVE LEAF AREAS OF TOMATO VARIETIES AT GRIFFITH, 1945–1946

Variety	Area of Typical Leaf (sq. in.)	Relative Total Leaf Area—		
		20.xii.45	18.i.46	18.ii.46
Adelaide Dwarf Red	3·0	2	12	37
Break O'Day	6·0	3	14	52
Grosse Lisse	5·2	2	9	52
H.E.S. 927M	9·6	5	30	86
Indiana Baltimore	6·8	3	13	48
Garden State	7·4	4	15	83
Morse's Special Early	6·4	5	22	88
Pearson 29–17	7·0	4	17	58
Red Cloud	6·4	4	20	70
Riverside	10·0	6	28	100
Stemless Pennred	6·4	2	13	48
Tatura Dwarf Globe	3·0	2	11	34

Riverside was the variety with the largest surface area of leaf blades, due to the large size of the individual leaves, rather than to their number. H.E.S. 927M and Morse's Special Early had relatively large areas of leaf. This was because of the large size of the individual leaves of H.E.S. 927M and because of their large number in the case of Morse's Special Early. Adelaide Dwarf Red, Tatura Dwarf Globe and Grosse Lisse had large numbers of small leaves, their total leaf areas being relatively small on account of the small size of individual leaves.

(f) Method of Fruit Production and Development

During the 1945–1946 season the position of the first blossom cluster on each observational plant was recorded. Throughout the season typical blossom clusters were marked. The numbers of flowers and the percentages of fruit set were recorded. These are shown in Table 7.

Adelaide Dwarf Red and Morse's Special Early averaged about seven blossoms per cluster, whereas Garden State and H.E.S. 927M averaged between three and four flowers in each blossom cluster.

There was a much better setting of fruit at Red Cliffs than at Griffith. At both centres Adelaide Dwarf Red and Tatura Dwarf Globe gave the highest percentage of blossoms that set fruit.

No appreciable varietal differences between the position of the first blossom cluster on the plant were noted, this being on the seventh to tenth internode on all varieties at Red Cliffs. Great variations occurred in the positions of the first blossom cluster within the same variety at Griffith (e.g. from the fifth to the sixteenth internode on the variety Indiana Baltimore). Typical blossom clusters of the twelve varieties are shown in Plate 3.

(g) Fruit Development

The average weight and size (diameter and depth) of the fruit of the varieties of tomatoes were recorded at Red Cliffs during the 1945–1946 season at the time of full ripeness.

The data obtained are set out in Table 8.

At the mid-season ripe stage fruit of Break O'Day and Stemless Pennred were the heaviest from Red Cliffs, each having an average weight of 172 grams. Adelaide Dwarf Red, Riverside and Grosse Lisse were the lightest, these having average weights of 123, 125, and 128 grams, respectively.

Adelaide Dwarf Red and Indiana Baltimore produced rather flattened fruit. Most of the other varieties had approximately the same ratio of depth to diameter; Grosse Lisse, Pearson 29–17 and Tatura Dwarf Globe being slightly deeper than the remainder.

At Griffith during the 1945–1946 season fruit was sampled on 7.ii.46 and 26.iii.46 and graded into three sizes, namely, diameters less than 1½ in., 1½–2½ in., and more than 2½ in. The percentage of the total weight for each variety is given for each size in Table 8. For the 7.ii.46 samples a noticeable feature is the comparatively high percentage of fruit in the desirable medium size (1½–2½ in.) of the varieties Break O'Day, Grosse Lisse, H.E.S. 927M, Pearson 29–17 and Riverside. Indiana Baltimore had a comparatively low percentage of medium-sized fruit at both dates. H.E.S. 927M and Riverside were the outstanding varieties at the 26.iii.46 sampling.

(h) Diseases Present

Fusarium wilt was the most common disease at Red Cliffs, being prevalent in the 1943-1944 season and in the 1945-1946 season, but with only a slight incidence in the remaining season. Fusarium wilt was not observed in any of the trials at Griffith.

Spotted wilt, a virus disease, occurred at both centres, most seriously at Griffith in the 1945–1946 season, when 60 per cent. of the plants of the varieties, Adelaide Dwarf Red, H.E.S. 927M, Morse's Special Early and Red Cloud showed symptoms. Pearson 29–17 had the lowest incidence (40 per cent.) of the varieties included in the trial, although Bounty, Rouge de Marmande, Stokesdale and Tatinter, growing in border rows of the trial, had lower proportions of the plants infected.

TABLE 7.—COMPARATIVE STUDIES IN BLOSSOM CLUSTERS AND FRUIT SETTING OF TOMATO VARIETIES AT RED CLIFFS AND GRIFFITH—1945–1946 SEASON

Variety	Red Cliffs								
	Average Position of First Blossom Cluster (Internode)	27.xii.45		7.i.46		17.i.46		29.i.46	
		Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit
Adelaide Dwarf Red	9 to 10	7·4	76·0	9·0	94·0	8·5	81·8	6·6	74·5
Break O'Day	8 to 9	5·0	20·2	4·2	79·5	6·1	71·0	3·9	55·9
Garden State	9 to 10	3·4	38·2	3·0	82·5	3·9	65·8	3·4	73·5
Grosse Lisse	8 to 9	3·8	42·8	5·1	89·6	5·8	78·7	6·2	68·3
H.E.S. 927M	8 to 9	3·2	40·3	3·5	86·8	4·0	77·8	3·5	74·6
Indiana Baltimore	8 to 9	4·6	40·2	4·8	80·9	7·3	65·2	5·2	69·8
Morse's Special Early	8 to 9	7·6	29·1	6·6	62·5	9·2	56·7	6·4	46·8
Pearson 29–17	8 to 9	3·2	31·3	3·9	79·8	4·2	65·8	4·2	71·3
Red Cloud	7 to 8	5·2	33·7	7·4	66·4	3·9	63·3	6·4	21·3
Riverside	8 to 9	3·3	23·2	3·6	67·5	4·8	67·3	4·7	73·3
Stemless Pennred	9 to 10	3·5	75·0	3·9	89·3	6·5	80·1	4·2	82·7
Tatura Dwarf Globe	7 to 8	4·1	67·4	4·9	96·6	6·9	87·2	5·3	73·2

Internodes measured from base of plant.

TABLE 7.—COMPARATIVE STUDIES IN BLOSSOM CLUSTERS AND FRUIT SETTING OF TOMATO VARIETEIS AT RED CLIFFS AND GRIFFITH—1945–1946 SEASON—*continued*

Variety	Average Position of First Blossom Cluster (internode)	Griffith																					
		1.i.46		14.i.46		22.i.46		29.i.46		4.ii.46		11.ii.46		18.ii.46		26.ii.46		5.iii.46		12.iii.46		19.iii.46		26.iii.46	
		Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit	Blossoms per Cluster	Percentage Setting Fruit
Adelaide Dwarf Red	Very variable between different plants of same variety	10·9	49·3	8·3	47·0	7·9	29·3	7·2	41·3	6·9	46·7	6·3	40·5	5·7	35·1	5·3	34·1	5·0	54·6	4·2	54·0	4·2	54·0	3·1	41·0
Break O'Day ..		6·0	17·8	8·8	15·9	6·1	18·5	7·4	11·3	6·3	32·8	6·8	21·1	6·8	29·9	5·8	35·1	6·0	36·4	5·9	31·9	2·8	23·5	3·3	10·3
Garden State ..		4·6	21·6	5·1	22·8	3·9	18·6	4·1	26·0	3·1	27·9	3·2	57·9	3·7	36·4	3·8	47·6	2·7	65·9	3·5	54·4	2·2	15·4	2·8	12·8
Grosse Lisse ..		4·3	23·8	6·2	33·8	5·8	35·0	7·1	54·8	6·3	43·4	6·6	41·8	6·9	50·6	5·9	42·9	5·4	50·4	6·1	41·8	2·2	40·9	3·5	16·5
H.E.S. 927M ..		4·4	32·5	4·2	22·3	3·9	16·2	3·5	39·6	3·5	36·1	2·7	30·6	3·2	30·0	3·2	41·3	3·1	48·4	2·6	37·0	2·0	11·1	2·3	13·5
Indiana Baltimore ..		6·0	17·8	6·7	13·9	6·6	23·0	6·9	26·0	7·5	23·9	6·6	21·6	5·8	25·6	5·0	44·7	5·0	43·3	6·0	44·4	2·8	33·8	2·9	8·8
Morse's Special Early		7·4	22·6	8·7	3·9	6·0	14·7	7·5	13·3	7·7	21·3	8·6	16·4	7·5	25·7	5·9	31·4	5·9	35·6	6·5	24·5	2·5	16·0	3·4	16·2
Pearson 29–17 ..		3·9	16·1	4·6	14·6	3·9	27·5	4·0	35·2	4·3	32·6	3·0	22·5	3·6	38·5	3·4	29·4	3·3	40·2	3·4	33·8	2·8	24·4	2·8	9·6
Red Cloud		6·4	21·3	7·0	18·7	6·8	25·4	6·2	27·6	5·8	32·1	5·1	33·7	5·3	36·1	4·6	25·6	4·8	31·1	5·3	27·0	3·6	17·7	3·5	7·1
Riverside		4·3	38·2	5·5	15·0	5·1	14·3	5·1	36·2	5·2	40·0	5·8	17·4	5·1	42·1	4·7	40·5	11·8	50·8	5·4	47·8	3·1	18·8	3·1	17·3
Stemless Pennred ..		3·5	42·9	3·9	32·0	4·0	19·4	5·8	34·7	5·2	38·7	3·6	31·9	4·4	36·5	4·9	65·4	4·2	50·9	4·1	50·7	2·4	44·1	2·1	23·6
Tatura Dwarf Globe		5·4	44·8	6·1	38·6	4·7	25·8	5·1	47·2	5·0	55·0	5·3	51·7	5·0	41·4	4·6	55·7	3·9	60·0	4·5	37·3	3·1	37·2	2·5	26·7

Internodes measured from base of plant.

TABLE 8.—SIZES OF TOMATOES AT RED CLIFFS AND GRIFFITH, 1945–1946

Variety	Red Cliffs			Griffith					
	18.ii.46			7.ii.46			26.iii.46		
	Average Weight (g.)	Average Diameter (in.)	Average Depth (in.)	Percentage of Fruit of Diameter			Percentage of Fruit of Diameter		
				< 1¼ in.	1¼–2¼ in.	> 2¼ in.	< 1¼ in.	1¼–2¼ in.	> 2¼ in.
Adelaide Dwarf Red	123	2·61	1·64	4	68	28	22	45	33
Break O'Day	172	2·73	2·08	12	76	12	35	65	0
Garden State	143	2·88	1·86	29	64	7	42	52	6
Grosse Lisse	129	2·50	2·00	6	84	10	25	61	14
H.E.S. 927M	146	2·60	2·03	4	84	12	8	81	11
Indiana Baltimore	151	2·71	1·87	29	31	40	27	39	34
Morse's Special Early	151	2·68	1·90	27	63	0	48	52	0
Pearson 29–17	158	2·59	2·04	10	83	7	20	70	10
Red Cloud	138	2·56	1·96	37	62	1	40	57	3
Riverside	125	2·45	1·89	21	78	1	17	83	0
Stemless Pennred	172	2·74	2·06	19	68	13	26	63	11
Tatura Dwarf Globe	156	2·64	2·07	32	68	0	37	63	0

In the other trials two virus diseases, spotted wilt and big bud, were present; the infection was light and patchy. The percentage of plants infected with these two virus diseases are shown in Table 9.

TABLE 9.—INCIDENCE OF THE MOST PREVALENT DISEASES AT RED CLIFFS AND GRIFFITH DURING THREE SEASONS

Variety	Red Cliffs				Griffith			
	Percentage of Big Bud		Percentage of Spotted Wilt		Percentage of Big Bud		Percentage of Spotted Wilt	
	1944–1945	1945–1946	1944–1945	1945–1946	1944–1945	1945–1946	1944–1945	1945–1946
Adelaide Dwarf Red	..	2·3	5·5	0.0	..	2·8	..	65·5
Bonnimar	..	..	..	..	0.0	..	0.0	..
Bonny Best	..	..	..	..	1·8	..	0.0	..
Bounty	..	..	..	..	1·8	4·3	0.0	15·2
Break O'Day	..	7·3	..	1·2	..	2·6	..	52·0
Garden State	..	6·1	..	4·6	..	5·4	..	54·4
Grosse Lisse	..	4·3	2·2	1·4	1·8	0·9	0.0	40·8
H.E.S. 927M	..	0.0	..	4·7	..	0·8	..	60·9
Indiana Baltimore	..	7·3	11·9	..	0·9	2·7	0.0	51·0
Marglobe	..	..	..	..	..	..	..	..
Morse's Special Early	..	1·2	6·2	3·6	..	6·6	..	68·6
Norton	..	..	..	..	0·9	..	0.0	..
Pan America	..	..	4·7	..	0.0	0.0	0.0	29·4
Pearson	..	..	10·1	..	0·9	..	0.0	..
Pearson 29–17	..	3·6	4·5	1·2	1·8	2·7	0.0	39·7
Pearson 32–5	..	..	..	..	0.0	..	0.0	..
Pennheart	..	..	3·7	..	0·9	5·6	0.0	52·2
Red Cloud	..	5·9	..	3·5	..	0·8	..	64·7
Riverside	..	1·2	..	2·4	4·0	0.0	0.0	55·5
Rouge de Marmande	..	..	..	..	..	2·2	..	28·2
Rutgers	..	..	9·3	..	1·8	..	0.0	..
Santa Clara Canner	..	..	..	..	..	..	..	..
San Marzano	..	..	..	..	7·5	..	3·0*	..
San Marzano Selection	..	..	..	..	3·6	..	0.0	..
Stemless Pennorange	..	..	..	..	4·6	..	0.0	..
Stemless Pennred	..	3·8	8·7	..	5·4	5·3	0.0	53·0
Stokesdale	..	..	..	..	2·8	..	0.0	21·9
Tatinter	..	..	..	..	1·8	0.0	0.0	21·9
Tatura Dwarf Globe	..	1·3	..	2·6	0.0	0.0	0.0	74·0
Wasatch Beauty	..	..	4·7	..	1·8	..	0.0	..
Washstate	..	..	..	..	1·8	..	0.0	..

* Average for commercial crops. No spotted wilt occurred in the variety trial.

3. Discussion

The desirable features in a tomato variety to be grown by the methods practised in the irrigation areas of Southern Australia include bush characters and fruit quality.

The bush should be small, erect and compact, producing a high yield of good quality, medium-sized fruit in such a position that they are not in direct contact with the ground and are shaded by the foliage. The ideal variety would also mature rapidly and continue to bear fruit over a long period. It would be resistant to the diseases that are prevalent in the district and to insect pests.

For most purposes, a smooth, bright red globular fruit is required. A strong skin and a number of small internal fruit cells are factors reducing losses in transport.

No one variety has all these desirable agronomic features, although each of them is possessed by at least one of the varieties studied in the trials. Thus the material is at hand for plant breeders to use in developing a variety more suitable for tomato production under furrow irrigation with the bushes unstaked and unpruned.

Pearson (various strains) yielded well in a number of field trials. H.E.S. 927M, Riverside, Pearson 29–17, Grosse Lisse and Break O'Day had fruit of satisfactory size and shape, whilst Red Cloud, Break O'Day and Stemless Pennred showed very good fruit colour. Morse's Special Early, Red Cloud, Pearson 29–17, and H.E.S. 927M had good internal fruit characters, although the pink colour of H.E.S. 927M rendered it commercially unsuitable. Adelaide Dwarf Red, Tatura Dwarf Globe, H.E.S. 927M and Pearson 29–17 had satisfactory types of bush. Garden State, Bounty, Tatura Dwarf Globe, and the so-called Chinese types were among the earliest varieties.

4. Acknowledgments

The work reported in this paper was suggested by the Vegetable Problems Committee, C.S.I.R., and was conducted under the supervision of Mr. E. M. Hutton, of the Division of Plant Industry.

The 1943–1944 trial at Griffith was conducted by Mr. K. Spencer, of the Griffith Research Station. The trial at Katherine was conducted by Lieut. H. Scott–Young at the Australian Army Farm. The co-operation of the Mildura Shire Council in making available the land at Red Cliffs is gratefully acknowledged. The photographs published are the work of Miss Z. Lasscock, of the Griffith Research Station.

5. References

Doolittle, S. P. (1943).—Tomato Diseases. U.S.D.A. Farmers' Bull., No. 1934.

Hubble, G. D., and Crocker, R. L. (1941).—A Soil Survey of the Red Cliffs Irrigation District. Coun. Sci. Ind. Res. (Aust.), Bull. No. 137.

Norris, D. O. (1947).—The Strain Complex and Symptom Variability of Tomato Spotted Wilt. Coun. Sci. Ind. Res. (Aust.), Bull. No. 202.

Taylor, J. K., and Hooper, P. D. (1938).—A Soil Survey of the Horticultural Soils in the Murrumbidgee Irrigation Areas, New South Wales. Coun-Sci. Ind. Res. (Aust.), Bull. No. 118.

Appendix I

The Mean Maturity Period

The Mean Maturity Period was determined as follows:—The weight of fruit was recorded for each date of picking. For each picking date the weight of fruit in lb. was multiplied by the number of days from transplanting to picking. These products were added together, and their sum divided by the total yield in lb.

Example

Date of picking	13.ii.46	21.ii.46	4.iii.46	11.iii.46	19.iii.46	26.iii.46	2.iv.46	9.iv.46	13.iv.46	Total
Days from transplanting ..	87	95	106	113	121	128	135	142	146	..
Yield (lb.)	47·68	29·24	20·52	61·18	31·30	28·18	37·48	34·30	74·47	364·35
Days × Yield	4148·16	2777·80	2175·12	6913·34	3787·30	3607·04	5059·80	4870·60	10872·62	44211·78

Mean Maturity Period $= \frac{44211 \cdot 78}{364 \cdot 35} = 121$ days.

Effect of Ozone on Microbial Growth on Beef Muscle, and on the Flavour of Beef Fat

*By J. F. Kefford, M.Sc.**

Summary

Studies of the growth of micro-organisms on beef muscle slices and on artificial media, in the presence of ozone, established the importance of surface moisture content in determining the magnitude of the effect of ozone on microbial growth. Ozone applied for 3 hours daily in concentrations of 3–5 p.p.m. had no effect on bacterial growth at 1° to 5°C. on muscle at full moisture content and only a slight retarding effect at moisture contents around 180 per cent. (expressed as per cent. dry weight); but when the moisture content was below 150 per cent. a useful extension of storage life was possible, provided the ozonization commenced during the lag phase of bacterial growth.

Ozone treatment under the conditions mentioned produced a readily detectable taint in beef fat in 3-5 days and caused appreciable darkening of muscle pigments in 5-6 days.

A micro-method for the determination of ozone concentrations down to one part per million (p.p.m.) is described.

1. Introduction

During the years 1938-39, a critical study of the usefulness of ozone gas as a constituent of the atmosphere in cold storage chambers for beef was undertaken as an extension of the work carried out over a number of years on the gas storage of beef. The results of the investigation have not been reported previously because of the pressure of wartime assignments.

Ozone has powerful oxidizing properties which are responsible for its well-known germicidal and deodorizing actions, but which also cause deteriorative changes in some organic constituents of foodstuffs, for instance the fats and muscle pigments in meats. For some time ozone has been used in the cold storage industry for deodorizing purposes—for destroying residual odours in chambers and, lately, for removing fuel oil taint from refrigerated meat cargoes. In the cold storage of eggs the usefulness of ozone, in concentrations of the order of 1 p.p.m.†, in preventing off flavours and inhibiting external mould growth is generally recognized (9,22,28,32). Regarding however, the use of ozone in storage atmospheres for chilled meat there is a notable lack of agreement between workers in several centres.

Previous Work

The original application of ozone in the cold storage of meat is said to have followed an observation by Thiele in 1909, that a considerable reduction in the bacterial count on stored meat occurred when an ozonizer was installed in the ventilating duct of a plant in Cologne, Germany. A number of early German papers on the

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† Throughout this paper ozone concentrations are expressed in parts per million of air, by volume.

1 p.p.m. = 2·14 mg./cubic metre = 0·6 mg./cubic ft.

subject are reviewed by Kaess (20, 21); some workers reported favorably, and some unfavorably, on the use of ozone in meat rooms. In 1936, Ewell (7, 9) stated that it was common practice in Europe to hold meat at 31° to 34°F., for eighteen hours after dressing, in an atmosphere containing 5 p.p.m. of ozone, and in a lower concentration, of the order of 1 p.p.m., during subsequent storage. This treatment, it was claimed, ensured freedom from mould spoilage for periods up to three months.

Ewell (9, 10) has consistently advocated the use of ozone in meat ripening rooms but he has made only general statements regarding its bactericidal and mould-inhibiting powers. He claims, for instance, that at 38°F. and 90-92 per cent. relative humidity, the storage life of beef is extended from about two to eight weeks by maintaining a schedule of ozone treatment at concentrations of 2-3 p.p.m. for two hours every twelve hours, and that under these conditions no fat deterioration occurs. On the other hand, as a result of experiments on bacteria in pure culture on artificial media and on muscle, Haines (14, 15) came to the conclusion that "ozone is not of great value in inhibiting microbial growth on stored tissues" (16).

A comprehensive study of the use of ozone was made by Kaess (20) using a pilot-scale apparatus in which air, containing ozone, was circulated over test samples of beef muscle, each weighing about 5 lb. The variables studied were: ozone concentration, duration and frequency of ozonization, storage temperature, relative humidity, initial bacterial count, and type of tissue. At 3°C. (37·4°F.) and 90 per cent. relative humidity, microbial growth was significantly retarded by ozone concentrations of 2-5 p.p.m. applied for three hours daily, but discoloration of the muscle tissue was apparent in five days.

A patent on the use of ozone in storage atmospheres for chilled beef was granted to Nevanas (29), and Milton (27) has recently made unsupported claims for its effectiveness in concentrations of the order of 1 p.p.m. In connexion with the use of germicidal ultra-violet lamps in meat cool rooms, the positive effects observed on meat surfaces shaded from the rays have been attributed to the presence of ozone (26, 41).

The present work was commenced, therefore, in an attempt to resolve some of the contradictory opinions on the real usefulness of ozone in the cold storage of meat. Two aspects were of particular interest, namely:

(*a*) To determine whether ozone could replace carbon dioxide in the transport by sea of chilled beef. Important advantages of ozone in this connexion are that the gas could be generated in the chambers by means of compact apparatus, and, since it is present in very low concentrations, the requirements for gas-tightness in the chambers would be much less rigid, thus simplifying construction and operation. Carrigan (5) refers to the use of storage atmospheres containing both carbon dioxide and ozone.

(*b*) To investigate whether ozone was a suitable agent for controlling microbial growth on beef during the process of ripening or tenderizing, involving storage at temperatures of the order of 40°F. (11, 19).

Plan of Investigation

The immediate objects of the investigation were to define the conditions, if any, under which ozone would control microbial growth on beef to an extent sufficient to give a useful extension of storage life, and to determine whether ozone treatment under these conditions would cause fat deterioration.

An experimental programme was planned to cover the following variables: the ozone concentration, the temperature and relative humidity of storage, the surface moisture content of the beef samples, and the nature of the microbial contamination.

A weakness in the earlier work on this subject was the absence of control of the surface moisture content of the meat samples used. In order to make a valid comparison of the growth rates of organisms in air and in ozonized air, it was essential that the surface moisture contents of the control and the ozone-treated samples should be the same throughout an experiment (34). The samples used therefore were very thin slices of beef muscle in aqueous vapour pressure equilibrium with the storage atmosphere.

An additional criticism which may be levelled against some of the previous work is that the ozone concentration in the vicinity of the stored products was not determined directly but calculated according to the degree of dilution of the entering concentration. Ewell (6, 8) determined ozone concentrations in cold rooms by exposing starch-iodide papers, and Kaess (20) used a potassium iodide absorption method requiring a sample of about 20 litres. For the present work an analytical method was sought which, in a gas sample of 500 ml., would determine ozone concentrations down to 1 p.p.m. with an accuracy of the order of $\pm$ 0·1 p.p.m. The method was also required to be reasonably rapid so that, if necessary, frequent adjustments and checks could be made to maintain the ozone concentration in a chamber at a desired level.

2. Determination of Ozone Concentrations

A number of analytical methods which had been developed for the determination of ozone concentrations in the ordinary atmosphere were examined for suitability according to the requirements mentioned.

Fluorescein Method.—Benoist (2) originated a method for the determination of ozone based on the extinction by ozone of the fluorescence of alkaline fluorescein solution. Tests of this method, however, confirmed the finding of Allen (1) that there is no reliable stoichiometric relation between the amount of ozone absorbed and the amount of fluorescein destroyed.

Nitrite Method.—The oxidation of sodium nitrite to nitrate by ozone in the presence of a manganous sulphate catalyst is the basis of an analytical method developed by Usher and Rao (39) and later used by Gorodetzkii (12). The method was not sufficiently sensitive at low ozone concentrations.

Dihydroacridine Method.—In a method described by Konstantinova-Schlezinger (23), ozone reacts with dihydroacridine in alcoholic solution to give acridine, the fluorescence of which is measured by

visual photometry. The elaborate precautions stated to be necessary to obtain good results by this method made it unsuitable for the present purpose.

Butyraldehyde Method.—Briner and Perrottet (4) developed a method for ozone analysis based on the catalytic oxidation of butyraldehyde in solution in iso-octane. The method was not favoured since the procedure was inherently time-consuming.

Potassium Iodide Method.—Ozone reacts with alkaline potassium iodide solution liberating one molecule of iodine for each molecule of ozone absorbed (1). The reliability of methods based on this reaction for estimating moderate concentrations of ozone is generally accepted; for instance Briner and Paillard (3) estimated accurately concentrations down to 500 p.p.m. By adapting the method on a microscale, according to the procedure to be described, it was successfully used to estimate ozone concentrations down to 1 p.p.m. Since this work was completed, potassium iodide absorption methods for the determination of very low concentrations of ozone have been recommended by Thorp (38) and Regener (33). Also Paneth *et al.* (30, 31) developed novel methods of ozone analysis which may have been applicable to the present problem.

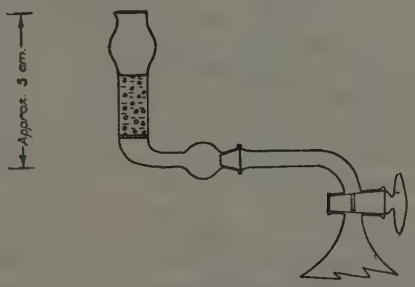


FIG. 1.—Microbubbler for ozone determination.

Analytical Procedure.—A sample of air containing ozone was taken in a 500 ml. gas sampling bulb and a microbubbler was fitted directly to the bulb by means of a standard ground-glass joint. The bubbler, illustrated in Figure 1, was made from a piece of 7 mm. Pyrex glass tubing in which a sintered glass plate was inserted by a procedure similar to that described by Stone and Weiss (37). In the bubbler was placed 1 ml. of 5 per cent. potassium iodide solution in 0·025N sodium hydroxide. The porosity of the sintered plate was such that the solution remained above it. By displacement with water from a constant level reservoir the gas sample was bubbled through the potassium iodide solution during a period of about ten minutes. The bubbler was then detached and the solution transferred, by blowing and rinsing, into a 10 ml. beaker so that the total volume was 2-3 ml. After acidification with two drops of N H_2SO_4 and the addition of two drops of 0·5 per cent. starch solution, it was titrated with 0·005N sodium thiosulphate solution from a 0·25 ml. microburette of the horizontal capillary type.

The accuracy of this micromethod was checked in the following way: Ozonized air containing about 0·1 per cent. of ozone was analysed according to the procedure recommended by Briner and Paillard (3). A sample was taken in a gas sampling bulb and potassium iodide solution was introduced directly into the bulb by cooling it in an ice-bath. After shaking for several minutes the potassium iodide solution was rinsed out and titrated with sodium thiosulphate solution. Accurate dilutions were then prepared from the ozonized air and analysed by the micromethod described. The concentrations found were compared with those calculated from the rate of dilution. In this way the accuracy of the method was found to be $\pm 0{\cdot}2$ p.p.m. on ozone concentrations down to 1 p.p.m. The method was reasonably rapid since, by using two samplers and two bubblers simultaneously, an analysis in duplicate could be made in fifteen minutes.

3. Experimental Methods

(*a*) *Equipment*

The apparatus set up to carry out storage experiments in air and in ozonized air is illustrated in Figure 2. All portions of the apparatus which came in contact with ozone were made of glass and connected by standard ground glass joints. Air was circulated through the system by means of a vacuum pump and there was a slight negative pressure of the order of 5 inches of water. A pressure regulator F, of the type described by Willson (40), maintained a constant rate of air flow. Air entering the system at A was brought to the required relative humidity by bubbling through washbottles containing sulphuric acid solution, of the appropriate concentration as indicated in Table 1, distributed on glass wool. All sulphuric acid solutions used in the system contained a little dichromate to prevent the evolution of sulphur dioxide.

At C and L are shown the two 10-litre desiccators which were used as storage chambers, each containing, in the lower portion, glass wool and sulphuric acid solution. The rate of air flow through the two desiccators was governed by the cocks E and G and measured on the capillary flowmeters D and H. The entering air stream divided at B, portion passing through chamber C and portion through chamber L, in each case bubbling through the sulphuric acid solution in the bottom of the desiccator. The trap Y, also containing sulphuric acid solution, prevented any passage of ozonized air into the chamber C.

An additional air stream entered the system at T and passed through the ozonizer W (see below) at a rate controlled by the cock V and measured on the flowmeter U. To attain the low concentrations of ozone required, the ozonized air was diluted with air entering at X, at a rate governed by the cock S, and measured on the flowmeter R. The greater part of this stream of ozonized air passed to waste through the washbottle Q, but a small leak was taken through the flowmeter P, at a rate controlled by the cock N, brought to the required relative humidity in the washbottle O and passed into the main airstream at M.

The washbottles J and Q contained a solution of potassium iodide, sodium thiosulphate and starch, which absorbed the residual ozone and protected the rubber tubing in the system beyond these points. When a blue colour appeared the solution was renewed.

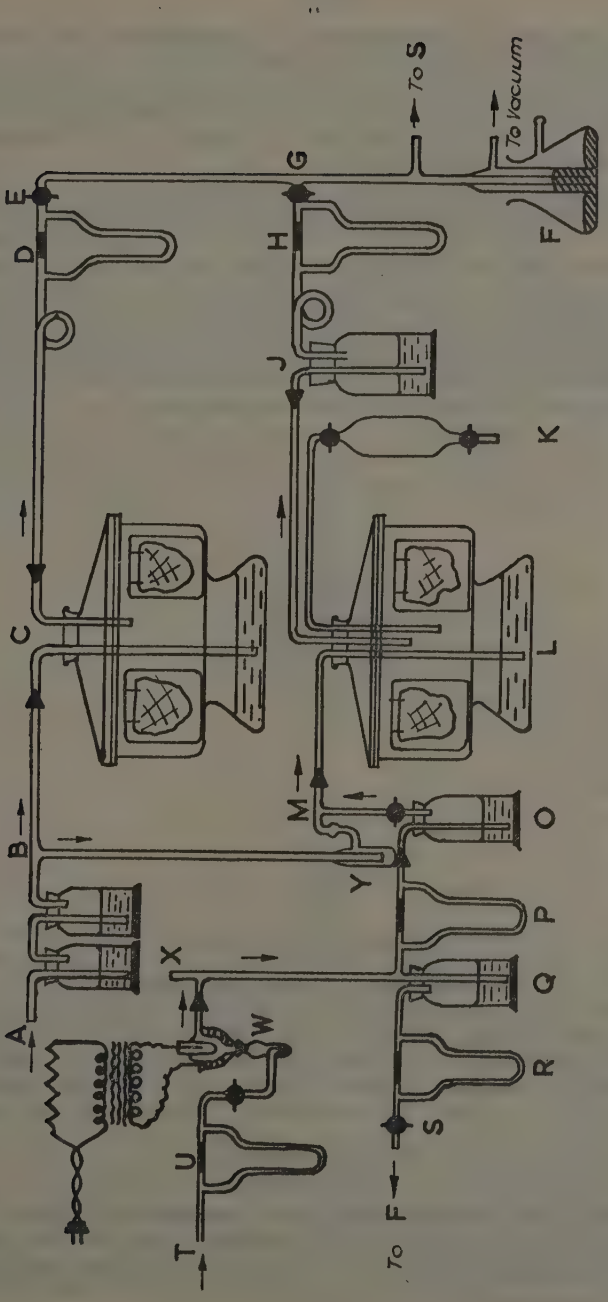


FIG. 2.—Apparatus for storage experiments in ozone atmospheres.

The atmosphere in the desiccator L was sampled for ozone analysis by running the water out of the gas sampler K.

Ozonizer.—A small all-glass ozonizer specially designed to give the low ozone concentrations required is illustrated in Figure 3. Even with this small generator a rather complicated dilution procedure was necessary as noted above.

The inner and outer tubes of the ozonizer contained 1 per cent. copper sulphate solution as an electrolyte and a cooling medium. A "silent" discharge was created across the annular space between the internal glass surfaces by passing 5,000 volts from a transformer, of the type used for "neon" signs, with a resistance of 500 ohms in the primary circuit. By using electrodes in the form illustrated sparking was eliminated. The bubbler contained concentrated sulphuric acid to dry the entering air and so minimize the possibility of forming nitrogen oxides. In repeated tests it was impossible to detect oxides of nitrogen in the ozonized air from this generator.

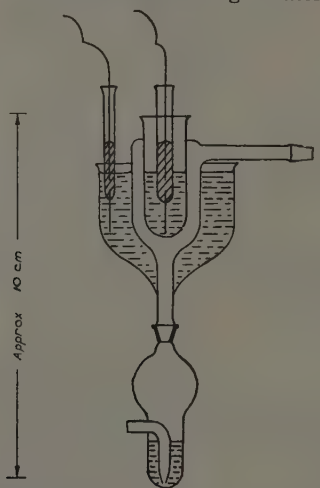


FIG. 3.—Small all-glass ozonizer.

(b) Schedule of Ozone Treatments

It was not practicable to arrange continuous ozone treatments with regular checking of the ozone concentration; therefore, throughout the present studies ozone was applied according to an intermittent schedule, for three hours in each 24 hours. Kaess (20) also adopted this schedule; he found that ozonization for three hours daily with concentrations of about 5 p.p.m. did not cause as great a retardation of bacterial growth as continuous ozonization, but that the effect was just as great as that of ozonization for six hours daily.

Ozone Concentrations.—The highest concentration used in the storage experiments was 5 p.p.m. If this concentration had a retarding effect on microbial growth under a given set of storage conditions, the effect of a concentration of 3 p.p.m. was tried, and then, in some cases, a concentration of 1 p.p.m. also.

In the apparatus described it was possible to control the ozone concentration so that the average concentration over the three-hour period was within ± 0·2 p.p.m. of the desired value; but there might be variations of the order of 20 per cent. during short periods when adjustments to the flow rates were being made.

(*c*) *Storage Temperatures*

The apparatus was set up in a cold room which was maintained either at 5°±0·1°C. (41°F.) or at 1°±0·1°C. (33·8°F.).

(*d*) *Meat Samples*

The test samples were thin slices of the *biceps femoris* muscle of the ox, mounted on wire hooks on metal frames, and brought to a moisture content in equilibrium with the relative humidity of the storage atmosphere by means of the techniques described by Scott (34).

Muscle slices in equilibrium with atmospheres of 99·3 per cent., 98·5 per cent., 97·5 per cent., and 95 per cent. relative humidity were used, and the corresponding moisture contents are shown in Table 1; also tabulated are the concentrations of sulphuric acid solutions having aqueous vapour pressures equivalent to the relative humidities required.

TABLE 1.

RELATION BETWEEN SULPHURIC ACID CONCENTRATION, RELATIVE HUMIDITY, AND MUSCLE MOISTURE CONTENT

H_2SO_4 Concentration (g. in 100 g.H_2O)	Relative Humidity (Per cent.)	Approximate Range of Muscle Moisture Content	
		(Per cent. dry weight)	(Per cent. wet weight)
2·00	99·3	290–315	75–76
4·06	98·5	185–205	65–67
6·50	97·5	120–135	54–58
11·90	95·0	73–77	42–44

The relative humidity of the atmosphere over sulphuric acid solutions of the same composition was assumed to be approximately constant between 1°C. and 5°C., and the muscle moisture contents also were found to be independent of temperature in this range.

As Scott (34) shows, the muscle moisture content is reasonably constant at a given relative humidity and it is convenient to refer to it in terms of the relative humidity (r.h.) of the atmosphere with which it is in equilibrium.

(*e*) *Test Organisms*

The muscle slices were prepared under aseptic conditions and inoculated with pure cultures of several organisms which had been found frequently on the surface of beef prepared in Australian meat works and were known to be capable of relatively fast growth on beef at low temperatures.

The following strains were used:—Two strains of *Achromobacter*, No. 7 and No. 483; one strain of *Micrococcus*, No. 202; one strain of *Pseudomonas*, No. 451; an asporogenous yeast of the genus *Candida*, No. Y9; and the moulds *Penicillium* No. B59, and *Sporotrichum* No. B79. The growth of several of these strains under various conditions of relative humidity, temperature and carbon dioxide concentration has been followed by Scott (34, 35, 36).

The techniques described by Scott were used for inoculating the muscle slices, by spraying with bacterial suspensions, to give initial counts of approximately 1,000 organisms per sq. cm., and for estimating the populations by disc sampling and plate counting.

Agar Plates.—Some studies were also made of the effect of ozone on the growth of organisms on agar plates. Bacteria were grown on a nutrient beef extract peptone agar pH 7·2, yeasts were grown on the same medium with the addition of 5 per cent. glucose, and moulds were grown on Czapek's agar. Sterile surfaces in petri dishes were inoculated by the spraying method used for the muscle slices and the plates were stored over saline at 5°C. in the desiccators in the apparatus described. Bacterial and yeast populations were estimated from a sample of 9 discs each 1 sq. cm. in area. The growth of mould was followed by microscopic measurement of the colony diameter, the mean diameter of 15 colonies being estimated at each examination.

(*f*) *Method of Operation*

At the commencement of an experiment the equilibrated muscle slices were inoculated by spraying and samples were taken for determination of the initial bacterial count and the moisture content. Two frames were placed in each desiccator, each frame bearing 6 slices, and the desiccators were sealed. The air flow was started in each line and the rate registered on flowmeters D and H adjusted to 40 litres per hour, representing 4 changes of air per hour in each desiccator. The ozonizer was switched on and the flowrates on flowmeters P, R, and U adjusted to values previously determined to give approximately the ozone concentration required in chamber L. When the system had been in operation for 10 minutes, two gas samples were taken, as at K, and immediately analysed for ozone. In the early stages of an experiment the ozone concentration was followed almost continuously and frequent adjustments to the ozone input were required. The meat samples absorbed less ozone as storage continued so that a given setting gave steadily increasing ozone concentrations. Ewell (6) also observed a decreased absorption of ozone by meat previously exposed to ozone. It is for this reason that a rapid method of ozone analysis was essential for the present investigation. In the later stages of an experiment the ozone concentration was checked at intervals of 1 hour.

At the end of the 3-hour period of exposure to ozone, the ozonizer was switched off and the air flow stopped in both lines. On some occasions, particularly after the first ozonization, a sample was taken at this stage for a bacterial count. After 24 hours the cycle of bacterial sampling and ozonization was repeated and continued for the duration of the experiment, usually 5–10 days at 5°C. and 15–20 days at 1°C.

When an experiment was completed the moisture content of the muscle slices was again determined. In common with the experience of Scott (34), it was found that the final moisture contents were always higher than the initial moisture contents, but if the difference between the moisture contents of the control and the ozonized slices was greater than 10 per cent. the results of the experiment were rejected.

4. The Effect of Ozone on the Growth of Bacteria and Yeasts on Agar

The results of experiments on the growth of bacteria and yeasts on agar surfaces at 5°C. are shown in Table 2. The population (P) per sq. cm. of surface is tabulated at intervals of t hours from inoculation. In Figures 4A and 4B the results are illustrated graphically by plotting the logarithm of the population against the time from inoculation. The treatments referred to in Table 2 were as follows:—

Control: Received no ozone.

Treatment A: Received 5 p.p.m. of ozone for 3 hours daily, commencing immediately after inoculation.

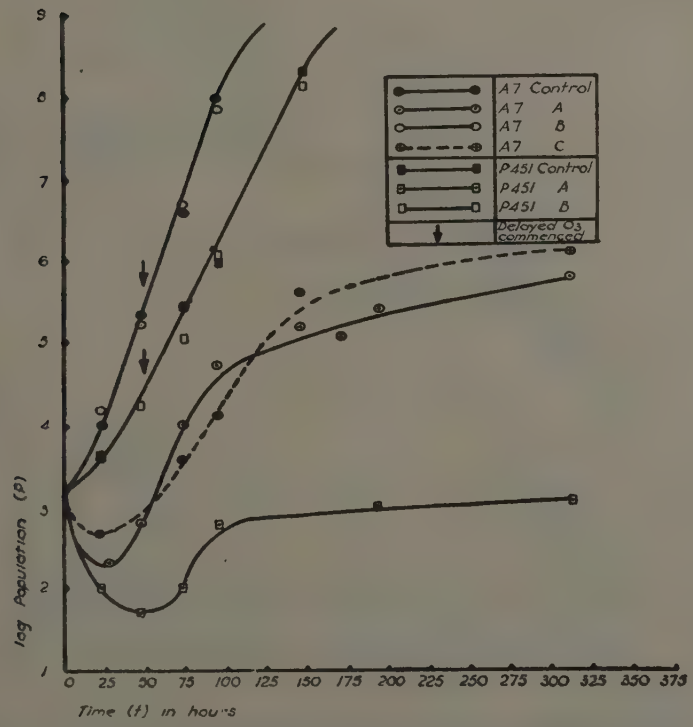


FIG. 4A.—The effect of ozone on the growth of micro-organisms on agar at 5° C.

Treatment B: Received 5 p.p.m. of ozone for 3 hours daily, commencing 48 hours after inoculation in the case of *Achromobacter* No. 7, *Pseudomonas* No. 451, and *Candida* sp. No. Y9, and 72 hours after inoculation in the case of *Micrococcus* No. 202.

Treatment C: Prior to inoculation the agar plates received 5 p.p.m. of ozone for a total period of 50 hours. After inoculation the plates were stored in air and received no further ozone.

Also recorded in Table 2 are the results of pH determinations on the agar media at the commencement and the conclusion of each experiment. In each case ozone treatment caused a substantial decrease in pH value.

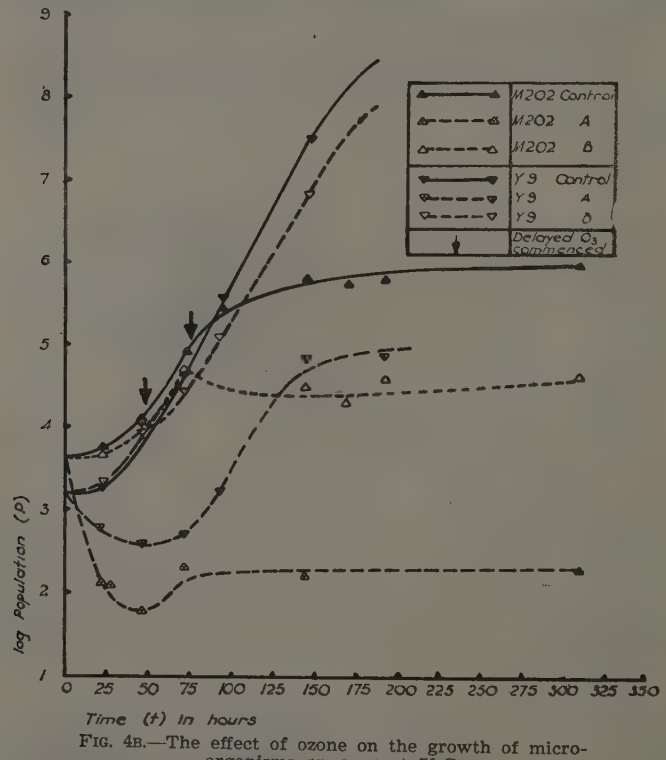

M202 Control
M202 A
M202 B
Y9 Control
Y9 A
Y9 B
Delayed O3 commenced
log Population (p)
Time (t) in hours
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350
1 2 3 4 5 6 7 8 9

FIG. 4B.—The effect of ozone on the growth of micro-organisms on agar at 5° C.

The organisms tested show varying degrees of susceptibility to ozone treatment. With *Achromobacter* No. 7, ozonization, commencing immediately after inoculation, caused some reduction in population

Table 2.

The Effect of Ozone Treatment, at a Concentration of 5 p.p.m., on the Growth of Organisms on Agar Plates at 5°C.

Time (t) (hours)	Population (P)												
	Achromobacter No. 7				*Pseudomonas* No. 451			*Micrococcus* No. 202			*Candida* No. Y9		
	Control	A	B	C	Control	A	B	Control	A	B	Control	A	B
.. ..	1,530	1,400	1,210	1,880	1,700	1,580	1,700	4,470	4,210	3,840	1,720	1,700	1,680
24 ..	1×10^4	160	$1{\cdot}5 \times 10^4$	470	4,000	100	5,230	5,750	140	4,180	2,120	600	1,800
28 ..	..	210	..	..	..	100	..	..	110	..	..	..	..
48 ..	$2{\cdot}2 \times 10^5$	600	$1{\cdot}6 \times 10^5$	..	9,000	50	$1{\cdot}8 \times 10^4$	$1{\cdot}3 \times 10^4$	60	9,000	$1{\cdot}2 \times 10^4$	400	$1{\cdot}3 \times 10^4$
74 ..	4×10^6	1×10^4	5×10^6	3,480	$2{\cdot}8 \times 10^5$	100	$1{\cdot}1 \times 10^5$	8×10^4	200	$4{\cdot}4 \times 10^4$	4×10^4	500	$2{\cdot}7 \times 10^4$
94 ..	1×10^8	$5{\cdot}5 \times 10^4$	7×10^7	$1{\cdot}3 \times 10^4$	1×10^6	600	$1{\cdot}2 \times 10^6$	$2{\cdot}7 \times 10^5$	..	2×10^4	$3{\cdot}6 \times 10^5$	1,800	$1{\cdot}2 \times 10^5$
146 ..	1×10^{10}	$1{\cdot}6 \times 10^5$	1×10^{10}	$4{\cdot}4 \times 10^5$	2×10^8	..	$1{\cdot}4 \times 10^8$	$6{\cdot}1 \times 10^5$	160	3×10^4	3×10^7	7×10^4	$6{\cdot}5 \times 10^6$
170 ..	..	$1{\cdot}2 \times 10^5$	..	..	..	..	..	$5{\cdot}2 \times 10^5$	..	2×10^4	..	..	..
192 ..	..	$2{\cdot}6 \times 10^5$	..	..	..	1,000	..	$6{\cdot}2 \times 10^5$	..	4×10^4	..	$7{\cdot}5 \times 10^4$	..
312 ..	..	$6{\cdot}5 \times 10^5$	..	$1{\cdot}4 \times 10^6$	..	1,150	..	9×10^5	200	$4{\cdot}5 \times 10^4$	..	..	..
Initial pH..	7·2	7·2	..	7·2	..	7·2	7·2	7·2	7·2	7·2	7·2	7·2	..
Final pH ..	7·0	5·4	..	5·9	..	5·2	6·2	7·0	5·2	5·5	7·1	5·0	..

and retarded the subsequent growth. A curve of very similar form was obtained for the growth of this organism on agar plates ozonized prior to inoculation. Delayed ozonization caused no retardation of the growth of *Achromobacter* No. 7 and *Pseudomonas* No. 451, but ozonization commencing immediately after inoculation caused a substantial reduction in the population of the latter organism and greatly restricted later growth. With *Micrococcus* No. 202, delayed ozonization caused a cessation of growth, while immediate ozonization caused a drop in population and practically no further growth occurred. Some retardation of the growth of the yeast *Candida* sp. No. Y9 occurred when delayed ozonization commenced, but subsequent growth was not appreciably retarded. The growth of the cultures ozonized immediately after inoculation followed a course similar to *Achromobacter* No. 7.

Since *Achromobacter* appeared to be the most resistant of the organisms tested to the effects of ozone treatment it was used for most of the studies on muscle slices. Haines (13) also found *Achromobacter* to be less susceptible to ozone than a number of other organisms.

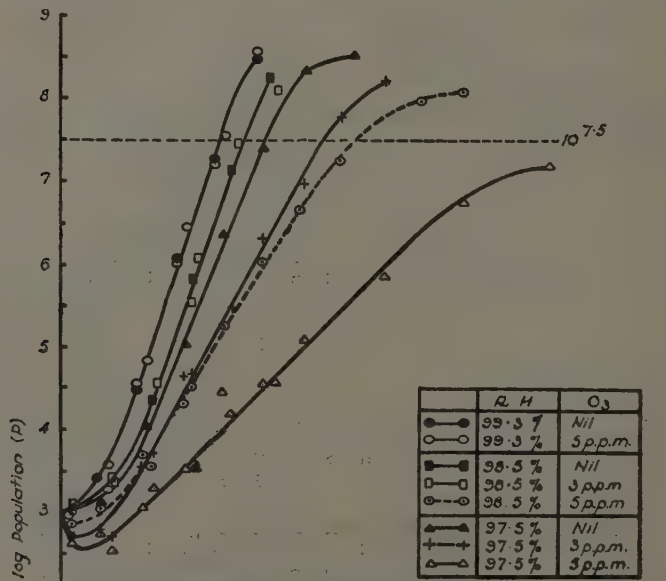


FIG. 5.—The effect of ozone on the growth of *Achromobacter* No. 7 at 5° C.

5. The Effect of Ozone on the Growth of Bacteria on Muscle

Typical results of studies of the effect of ozone concentrations of 3 and 5 p.p.m., applied for 3 hours daily, on the growth of *Achromobacter* No. 7 on muscle slices at 5°C. are set out in Table 3 and Figure 5.

TABLE 3

THE EFFECT OF OZONE ON THE GROWTH OF *Achromobacter* No. 7 AT 5°C.

Relative Humidity	Ozone Concentration					
	Nil		3 p.p.m.		5 p.p.m.	
	t	*P*	*t*	*P*	*t*	*P*
99·3%	0	1,030	..	..	0	1,010
					4	850
	21	2,700	..	..	21	2,700
					27	3,720
(Moisture Content =	45	3×10^4	..	..	45	$3{\cdot}4 \times 10^4$
290–315%)					51	$6{\cdot}5 \times 10^4$
	69	$1{\cdot}2 \times 10^6$	..	..	69	1×10^6
					75	$2{\cdot}8 \times 10^6$
	93	$1{\cdot}8 \times 10^7$	..	..	93	$1{\cdot}6 \times 10^7$
					98	$3{\cdot}4 \times 10^7$
	117	$3{\cdot}1 \times 10^8$	..	..	117	$3{\cdot}6 \times 10^8$
98·5%	0	980	0	1,140	0	1,300
			6	1,290	4	700
					24	1,150
	29	2,600	32	2,300	28	1,900
(Moisture					48	4,900
Content =	53	$2{\cdot}2 \times 10^4$	57	$3{\cdot}6 \times 10^4$	53	3,500
185–205%)					72	$2{\cdot}1 \times 10^4$
	77	$6{\cdot}6 \times 10^5$	77	$3{\cdot}5 \times 10^5$	76	$3{\cdot}2 \times 10^4$
	101	$1{\cdot}4 \times 10^7$	82	$1{\cdot}2 \times 10^6$	96	$1{\cdot}7 \times 10^5$
	125	$1{\cdot}8 \times 10^8$	105	3×10^7	120	$1{\cdot}1 \times 10^6$
			129	$1{\cdot}3 \times 10^8$	144	$4{\cdot}6 \times 10^6$
					168	$1{\cdot}8 \times 10^7$
					216	9×10^7
					240	$1{\cdot}2 \times 10^8$
97·5%			0	780	0	820
	0	990	5	500	6	420
			24	580	24	530
	24	1,320	30	520	29	330
			48	3,500	48	1,200
(Moisture	48	$1{\cdot}13 \times 10^4$	53	5,000	54	2,000
Content =			72	$4{\cdot}3 \times 10^4$	72	3,200
120–135%)	72	$1{\cdot}1 \times 10^5$	77	$4{\cdot}6 \times 10^4$	78	3,400
			96	$1{\cdot}5 \times 10^5$	96	$2{\cdot}9 \times 10^4$
	96	$2{\cdot}5 \times 10^6$	101	3×10^5	100	$1{\cdot}5 \times 10^4$
					120	$3{\cdot}3 \times 10^4$
	120	$2{\cdot}6 \times 10^7$	120	2×10^6	126	$3{\cdot}5 \times 10^4$
			144	9×10^6	144	$1{\cdot}2 \times 10^5$
	146	$2{\cdot}1 \times 10^8$	168	$5{\cdot}8 \times 10^7$	192	$6{\cdot}7 \times 10^5$
					240	$5{\cdot}5 \times 10^6$
	175	$3{\cdot}2 \times 10^8$	192	$1{\cdot}6 \times 10^8$	292	$1{\cdot}5 \times 10^7$

TABLE 4

THE EFFECT OF OZONE ON THE GROWTH OF *Achromobacter* No. 7, AT 1°C. AND 98·5 PER CENT. RELATIVE HUMIDITY

Ozone Concentration.									
Nil.		1 p.p.m.		3 p.p.m.		5 p.p.m.		5 p.p.m. delayed.	
t	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*
0	1,300	0	1,500	0	1,070	0	1,750	0	1,450
				6	540	6	400		
24	1,980	27	1,000	24	720				
				27	820				
48	5,600	48	1,640	48	1,500	47	600		
				53	1,500				
		75	$1{\cdot}1 \times 10^4$	72	4,700	77	1,000	72	$3{\cdot}1 \times 10^4$
96	$1{\cdot}9 \times 10^5$			96	$1{\cdot}1 \times 10^4$				
				101	9×10^3				
120	$6{\cdot}3 \times 10^5$	120	$2{\cdot}1 \times 10^5$	120	$2{\cdot}8 \times 10^4$			120	$8{\cdot}9 \times 10^4$
138	$2{\cdot}5 \times 10^6$	147	$8{\cdot}2 \times 10^5$	168	$1{\cdot}4 \times 10^5$	148	2,110	138	$1{\cdot}1 \times 10^6$
172	$1{\cdot}5 \times 10^7$	172	$3{\cdot}2 \times 10^6$	216	$1{\cdot}1 \times 10^6$	198	1×10^4	172	$8{\cdot}3 \times 10^6$
234	$7{\cdot}2 \times 10^8$	196	$2{\cdot}3 \times 10^7$	256	$8{\cdot}4 \times 10^6$	246	$2{\cdot}6 \times 10^4$	234	$3{\cdot}2 \times 10^8$
284	$2{\cdot}8 \times 10^9$	240	8×10^7	312	7×10^7	312	$1{\cdot}9 \times 10^5$	284	$1{\cdot}8 \times 10^9$
				360	$9{\cdot}5 \times 10^7$	362	$5{\cdot}8 \times 10^5$		
						409	$3{\cdot}7 \times 10^6$		
						454	$6{\cdot}9 \times 10^6$		

In Table 4 and Figure 6 is shown the growth of *Achromobacter* No. 7, at 1°C. and 98·5 per cent. r.h., as affected by ozone concentrations of 1, 3, and 5 p.p.m., applied for 3 hours daily commencing immediately after inoculation, and as affected by delayed ozonization with 5 p.p.m., for 3 hours daily, commencing 72 hours after inoculation.

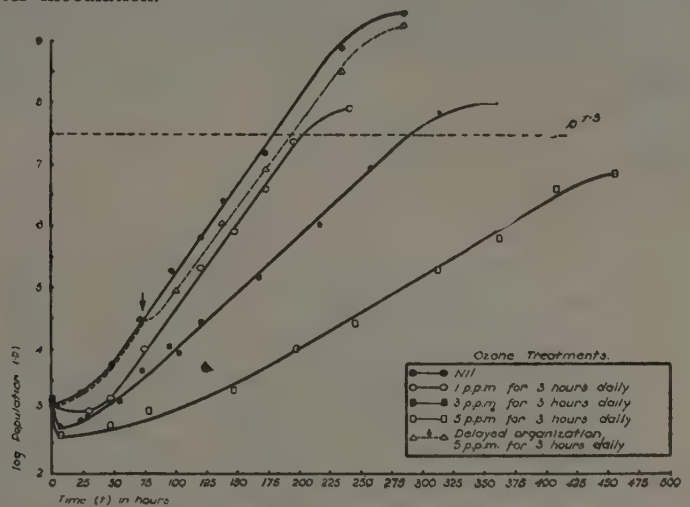

log Population (P)
Time (t) in hours
Ozone Treatments.
Nil
1 p.p.m. for 3 hours daily
3 p.p.m. for 3 hours daily
5 p.p.m. for 3 hours daily
Delayed organization, 5 p.p.m. for 3 hours daily
7·5

FIG. 6.—The effect of ozone on the growth of *Achromobacter* No. 7 at 1°C. and 98·5 per cent. relative humidity.

Table 5 and Figure 7 express the results of some confirmatory studies using *Achromobacter* No. 483 as the test organism. The effects of ozone at a concentration of 3 p.p.m. on the growth of this organism at 5°C., with relative humidities of 98·5 per cent. and 97·5 per cent. are shown.

(*a*) *Limit of Storage Life*

For the purpose of comparing the storage life of meat samples held in air and in ozonized air, Kaess (20) defined a limit of acceptability when the bacterial count reached $10^{7 \cdot 5}$ organisms per sq. cm. Scott (34) has shown that this co-called "slime point" has little significance with respect to the appearance of visible growth of *Achromobacter*, particularly at the lower moisture contents. The same limit has been used herein, however, as a convenient arbitrary level of bacterial population at which to estimate the relative extension of storage life brought about by ozone treatment.

(*b*) *The Effect of Surface Moisture Content*

At full muscle moisture content (99·3 per cent. r.h.), ozone at a concentration of 5 p.p.m. had no effect on the growth of *Achromobacter* No. 7 at 5°C. In Figure 5 the curves for growth in air and in ozonized air are coincident. Haines (14), working with lean meat samples at full moisture content (100 per cent. r.h.), found that continuous ozonization with 10 p.p.m. had no effect on slime formation at 0°C.

With a relative humidity of 98·5 per cent. at 5°C., 3 p.p.m. of ozone had no effect on the growth of *Achromobacter* No. 7 (Figure 5), and *Achromobacter* No. 483 (Figure 7), but 5 p.p.m. prolonged the storage life by about 75 per cent.

TABLE 5

THE EFFECT OF OZONE ON THE GROWTH OF *Achromobacter* No. 483 AT 5°C.

Relative Humidity	98%				97·5%			
Ozone Concentration	Nil		3 p.p.m.		Nil		3 p.p.m.	
	t	*P*	*t*	*P*	*t*	*P*	*t*	*P*
	0	840	0	760	0	1,000	0	920
			9	820			6	350
	23	1,180	23	910	24	1,350	24	400
			29	1,190			29	320
	47	$1·4 \times 10^4$	47	$2·4 \times 10^4$	48	2,750	48	1,000
			53	$2·9 \times 10^4$			54	1,380
	71	3×10^5	71	$3·5 \times 10^5$	72	$2·8 \times 10^4$	72	5,700
			78	$3·8 \times 10^5$			78	$1·2 \times 10^4$
	95	$3·9 \times 10^6$	95	5×10^6	96	$4·9 \times 10^5$	96	$4·4 \times 10^4$
							100	$3·8 \times 10^4$
	119	$1·2 \times 10^8$	119	$6·6 \times 10^7$	120	$5·3 \times 10^6$	120	$1·8 \times 10^5$
							126	$1·9 \times 10^5$
	143	9×10^8	143	$1·5 \times 10^9$	144	$6·5 \times 10^7$	144	1×10^6
					168	$3·3 \times 10^8$	168	$7·3 \times 10^6$
					192	$8·1 \times 10^8$	196	$2·2 \times 10^6$
							240	$6·7 \times 10^7$

When the relative humidity was reduced to 97·5 per cent. at 5°C., 3 p.p.m. of ozone showed a slight controlling effect on the growth of both *Achromobacter* strains, while 5 p.p.m. gave an approximately 3-fold extension of storage life.

Kaess (20), working at 3°C. and a relative humidity of 90 per cent, but with samples which were not in equilibrium with the storage atmosphere, observed an extension of storage life of 25–50 per cent. with 5 p.p.m. of ozone and no appreciable extension at ozone concentrations less than this. At 70 per cent. r.h. Kaess found that ozone had less effect than at 90 per cent. r.h., but in the absence of information on surface moisture contents it is difficult to interpret this result.

(*c*) *The Effect of Temperature*

At 1°C. studies were made at only one moisture level, 98·5 per cent. r.h., and under these conditions (Figure 6) ozone had a somewhat greater effect on the growth of *Achromobacter* No. 7 than at 5°C. With 5 p.p.m. of ozone the extension of storage life was about 3-fold and with 3 p.p.m. about 60 per cent.; 1 p.p.m. caused only a slight initial retardation of growth. Kaess (20) also observed that 5 p.p.m. of ozone had a greater retarding effect on bacterial growth at 0°C. than at 3°C.

(*d*) *The Effect of Delayed Ozonization*

In Figure 6 is shown the effect at 1°C. and 98·5 per cent. r.h., of delaying the commencement of ozonization until bacterial growth was well established. Whereas 5 p.p.m. of ozone applied for 3 hours daily from inoculation gave a 3-fold extension of storage life, the same ozone treatment commenced 72 hours after inoculation caused only a slight initial retardation of growth and the extension of storage life was insignificant. This result is very similar to those obtained on agar media (Figure 4).

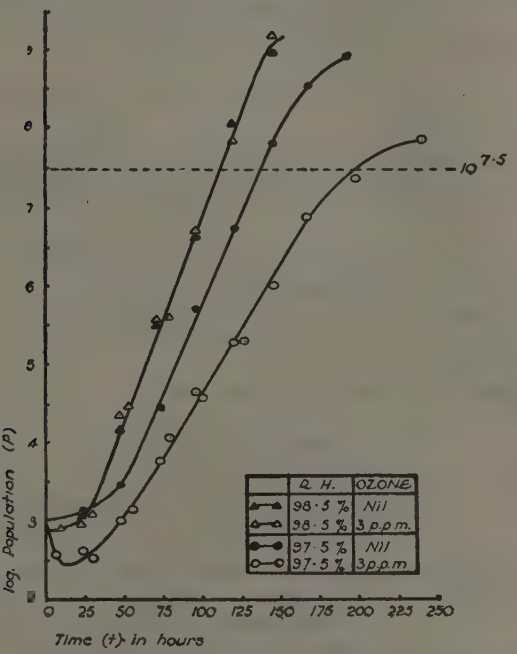


FIG. 7.—The effect of ozone on the growth of *Achromobacter* No. 483 at 5° C.

Haines (13, 15), studying bacterial growth on artificial media, found that the effects of ozone were most pronounced when it was applied during the lag phase of growth, and Kaess (20) noted a decreased effect when the commencement of ozonization was delayed for 24 hours.

(*e*) *The Form of the Growth Curves*

Examination of the curves representing the growth of bacteria on muscle slices and on agar surfaces in the presence of ozone reveals a general similarity of form. In those cases where a positive control

of bacterial growth was observed, the following effects of ozone treatment are distinguishable:—

(i) The first one or two ozonizations, applied during the lag phase of growth, exert more or less marked bactericidal effects. The growth curves reproduced by Kaess (20) show similar effects for ozone concentrations of 5 p.p.m., while with ozone concentrations as high as 200 p.p.m. a definite reduction in population occurred at each ozonization up to 4 days.

(ii) There is an extension of the lag phase to an extent which is greater with higher concentrations of ozone.

(iii) Growth in the logarithmic phase is significantly retarded by the higher ozone concentrations.

(iv) The higher ozone concentrations also reduce the maximum population.

Under the conditions of application in the present work ozone appears to act as an inhibitor of the type which affects both the lag period of the organisms tested and the subsequent rate of growth.

6. The Effect of Ozone on the Growth of Moulds

Sterile surfaces of Czapek's agar in petri dishes were inoculated with mould suspensions, washed from Czapek's agar slopes 7 days old and shaken with sand to break up clumps. Then the inoculated plates were treated as follows:—

Treatment A: The plates were stored in air at 25°C. until growth commenced. After 24 hours for *Penicillium* No. B59, and after 48 hours for *Sporotrichum* No. B79, the plates were transferred to storage at 5°C. The controls received no ozone while the ozonized plates received 5 p.p.m. of ozone for 3 hours daily.

Treatment B: These plates were placed immediately at 5°C., the controls receiving no ozone and the ozonized plates receiving 5 p.p.m. for 3 hours daily.

Typical results are shown in Figure 8 where the mean diameter in millimetres of 15 colonies is plotted against the time in hours from inoculation. When *Penicillium* No. B59 was allowed to commence growth at 25°C. ozone treatment caused a marked retardation of subsequent growth at 5°C., and when the plates were placed immediately at 5°C. no growth occurred in the presence of ozone during storage for 14 days. In the case of *Sporotrichum* No. B79 no growth occurred in the presence of ozone under either set of conditions. In these experiments also a decrease in the pH of the medium in the ozonized plates, from an initial value of pH 6·6 to a final value of pH 5·5–6·0, was observed.

A further experiment was performed in which agar plates were ozonized for a total period of 50 hours with 5 p.p.m. of ozone and then sprayed with *Penicillium* No. B59. In this case the mould growth

was not followed microscopically, but visible mould appeared on the control plates after 7 days at 5°C. and on the ozonized plates after 37 days.

The effect of ozone on mould growth on muscle slices was examined at 5°C. and 95 per cent r.h. Muscle slices with a moisture content of 75 per cent. were sprayed with a spore suspension of *Penicillium* No. B59 to give an initial count of approximately 500 per sq. cm. Some slices were stored in air and others ozonized with 5 p.p.m. of ozone for 3 hours daily. Visible mould growth appeared on the control slices on the 15th day, but had not appeared on the ozonized slices on the 25th day when the experiment was concluded.

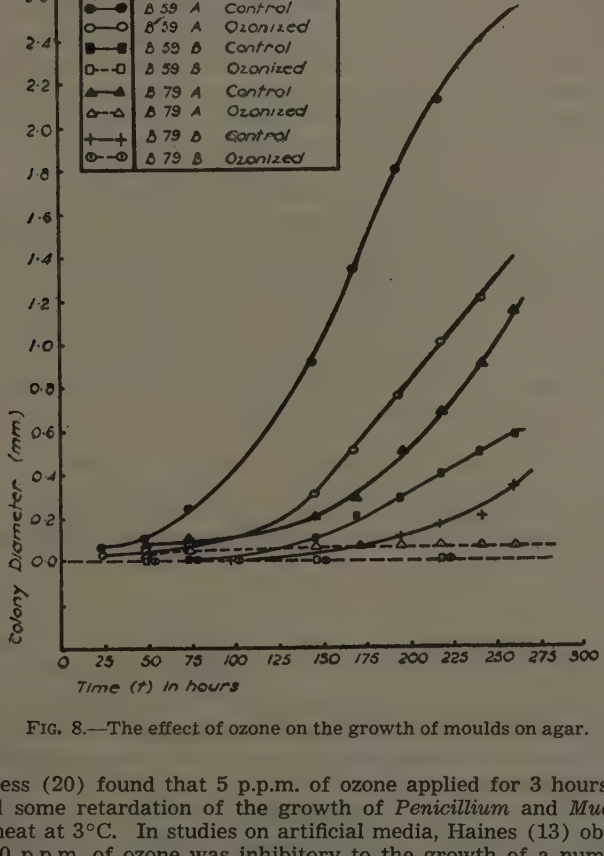

B 59 A Control
B 59 A Ozonized
B 59 B Control
B 59 B Ozonized
B 79 A Control
B 79 A Ozonized
B 79 B Control
B 79 B Ozonized
Colony Diameter (mm)
Time (t) in hours
0 25 50 75 100 125 150 175 200 225 250 275 300
0·0 0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6 1·8 2·0 2·2 2·4 2·6 2·8

FIG. 8.—The effect of ozone on the growth of moulds on agar.

Kaess (20) found that 5 p.p.m. of ozone applied for 3 hours daily caused some retardation of the growth of *Penicillium* and *Mucor* on lean meat at 3°C. In studies on artificial media, Haines (13) observed that 80 p.p.m. of ozone was inhibitory to the growth of a number of moulds at 0°C., and Lewis and Yesair (25) reported some positive effects at 8° to 10°C. with ozone concentrations as low as 0·5 p.p.m.

7. The Effects of Ozone on Media

It has already been mentioned that agar media treated with ozone suffered a marked decrease in pH value, which was probably, in itself, an important cause of the observed effects on microbial growth. It was interesting, also, to find that growth followed a very similar pattern on agar plates ozonized prior to inoculation and that similar changes in pH value occurred. Haines (15) observed that nutrient broth treated with ozone changed in reaction from pH7 to pH4–5 and failed to support microbial growth; when the pH was restored to its original value slow growth occurred and eventually produced a population as high as in untreated broth.

These observations may have some value in assisting to elucidate the mechanism of the germicidal action of ozone, which may depend entirely on chemical changes in the medium surrounding the organisms. If this is so, it is possible that an ozone treatment involving a short exposure to a high concentration of ozone would be as effective as treatment with low concentrations throughout the storage period. Heiss (17) discusses the mechanism of ozone action somewhat along these lines and suggests an ozone treatment in which 5 p.p.m. is applied continuously for 1 day and subsequently 1–2 p.p.m. for short periods whenever the cold room is opened.

8. The Effect of Ozone on Muscle Colour

No attempt was made in the present study to follow quantitatively the changes in muscle pigments brought about by ozone treatment; but visual observations indicated that samples ozonized for 3 hours daily with 3–5 p.p.m. of ozone showed a dull brownish-red colour on the 5th or 6th day, while the control samples retained a bright red colour until the 12th or 13th day. These observations are in agreement with those of Kaess (20), who found by means of photometric measurements that, with 5 p.p.m. of ozone at 3°C., discoloration of muscle tissue was apparent in 5 days.

9. The Effect of Ozone on the Flavour of Fats

The second purpose of the present project was to ascertain whether ozone, in the concentrations (3–5 p.p.m.) which had shown positive effects in controlling microbial growth, would cause deterioration in the flavour of beef fat.

Fat Samples

Slices of beef sternum fat, 5 mm. thick, were cut on a bacon slicer, under conditions as nearly aseptic as possible, and placed on petri dishes. The dishes were stacked in the desiccators in the apparatus described in such a way as to allow free access of ozone, and sampled at intervals for tasting by a panel of three tasters experienced in fat tasting. Some slices were also held at —10°C. to serve as controls in the tasting tests.

Tasting Tests

Each sample for tasting consisted of pieces cut from several slices. The samples were tasted cold (uncooked) and also hot, after cooking in a clean aluminium pan for 5 minutes until lightly browned. Three

samples only were tasted at one time, the sample held at −10°C. being tasted first, and between samples the tasters rinsed their palates with warm saline.

To record the results of the tasting tests the following scoring system was used:—

0 Indistinguishable from the control sample.
1 A very faint off-flavour.
2 A definite but slight off-flavour.
3 A definite off-flavour, distinguishable as ozone taint.
4, 5, 6 Ozone taint becoming more pronounced.
7, 8, 9, 10 Ozone taint very pronounced and fat becoming increasingly unpalatable.

The ozone taint mentioned is a very characteristic flavour recalling the odour of ozone; it has also been described as a "metallic" or "cucumber" flavour (25). The taint was always much less readily detectable in the cooked samples. It is probable that the light cooking process employed was less effective in removing the taint than cooking procedures such as roasting. However for the present purpose the limit of acceptability for normal use was taken to be when the cooked samples reached a flavour score of 3, representing a readily detectable but slight ozone taint. At this stage the uncooked samples usually scored 5–6, representing a pronounced ozone taint.

Results of Tasting Tests

The results of typical experiments are shown in Figure 9 which expresses diagrammatically the flavour deterioration of fat slices held at 5°C. and ozonized for 3 hours daily with concentrations of 3 p.p.m. and 5 p.p.m. The mean score for the three tasters is plotted against the storage time in hours. The results have been expressed in continuous curves, but it is necessary to point out that the process of flavour deterioration is not continuous but operates primarly during the 3-hour periods of ozonization.

With 5 p.p.m. of ozone the acceptability limit is reached in 3 days at the 4th ozonization, and with 3 p.p.m. in 5 days at the 6th ozonization. Similar experiments at 1°C. gave almost identical results. The ozone taint did not disappear from tainted fats during further storage in the absence of ozone.

Peroxide and aldehyde values (24) were determined on the fat samples throughout the storage experiments, but up to 5 days there was no significant difference between the values for ozonized and control fats. This result was not unexpected, since although Lea (24) found that 5 p.p.m. of ozone had a pronounced catalytic effect on the oxidation of beef fat, the induction period was still of the order of 15 days at 0°C. It is considered that the characteristic taint is a more serious factor limiting the use of ozone than its effects in promoting fat rancidity.

It is true that conditions in these experiments were particularly favourable for tainting. While tainting might occur at comparable rates on exposed surfaces of fat on beef cuts, it is reasonable to expect that carcass fat, protected by outer skin, would taint less readily. Ewell (9), for instance, claims that beef, treated with 3 p.p.m. of ozone for 4 hours daily, is held for 8 weeks without taint. On the other hand, Lewis and Yesair (25) found that exposure to ozone in concentrations as low as 0·3 p.p.m., for 4 days, produced off-flavours in various meat products.

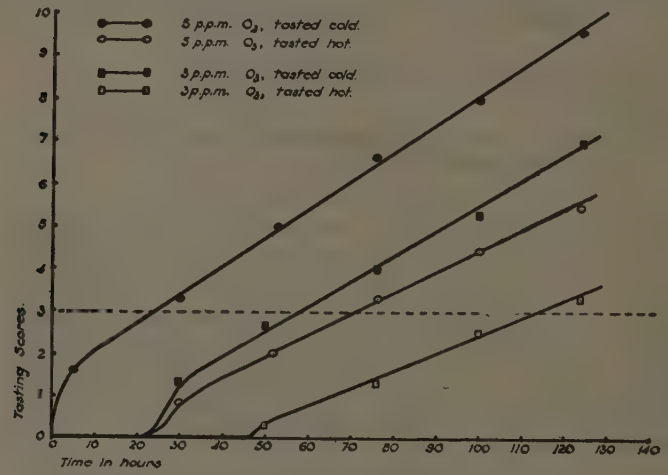


FIG. 9.—The effect of ozone on the flavour of beef fat.

10. Conclusions

The present work has established the importance of surface moisture content in determining the effect of ozone on microbial growth on beef muscle. It is highly probable that inadequate control of this factor was largely responsible for the discordant results obtained by previous workers in this field. Ozone applied for 3 hours daily in concentrations of 3–5 p.p.m. had no effect on bacterial growth at 1° to 5°C. on muscle at full moisture content and only a slight retarding effect at moisture contents around 180 per cent.; but when the moisture content was below 150 per cent. a useful extension of storage life was possible, provided the ozonization commenced during the lag phase of bacterial proliferation. Ozone treatment in the concentrations mentioned also considerably restricted mould growth on muscle and artificial media.

It is important to make it clear that the moisture contents referred to cannot be related directly to surface conditions on beef sides and cuts for several reasons, for example:—

(i) A technique for measuring the true surface moisture content of beef in the mass has not yet been devised.

(ii) The equilibrium humidity of the surface will not quite equal the relative humidity of the storage atmosphere.

(iii) There is evidence (18) that owing to the diffusion of dissolved substances away from the surface of beef in the mass, the relation between equilibrium humidity and water content is different from that in thin slices.

In view of the fact that significant controlling effects on microbial growth, even at the lower moisture levels, were not obtained with ozone concentrations less than 3–5 p.p.m., it is difficult to understand the claims of Mallman and Churchill (26) that an ozone concentration of 0·1 p.p.m. was inhibitory, unless continuous ozonization with concentrations as low as this is more effective than intermittent ozonization with higher concentrations. However, Kaess (20) records that continuous ozonization with 1 p.p.m. of ozone gave no greater inhibitory effect that treatment for 3 hours daily with 1·5 p.p.m. of ozone.

With regard to the application of ozone in the cold storage of meat, the present results indicate that useful inhibition of microbial growth is most likely to be obtained when ozone is applied in concentrations of the order of 5 p.p.m. immediately after the initial chilling when the contaminating organisms are still in the lag phase and when the surface moisture content is reduced. In reports (7, 9) of the successful use of ozone under commercial conditions in Germany and America, it is stated that meat was ozonized immediately after killing and dressing, and it is evident that subsequent storage conditions favoured a considerable loss of surface moisture, since Ewell (9) notes that mould spoilage predominated and implies that the use of ozone was not successful under conditions of high humidity.

In chilled beef carriage by sea, under conditions of tight stowage, it is not likely that surface moisture contents could be maintained at a level low enough to secure a useful extension of storage life.

In any case, the fact that ozone, in those concentrations which were effective in controlling microbial spoilage, produced deteriorative changes in fat flavour and muscle colour within a few days suggests that ozone has limited application in the cold storage of meat.

11. Acknowledgments

This work would not have been possible without the skilled assistance in bacteriological techniques of H. A. McDonald.

12. References

(1) Allen, N. (1930).—*Ind. Eng. Chem.* (*Anal. Ed.*) **2**: 55.

(2) Benoist, L. (1919).—*C.R. Acad. Sci., Paris* **168**: 612.

(3) Briner, E., and Paillard, H. (1935).—*Helv. Chim. Acta* **18**: 234.

(4) ———— and Perrottet, E., (1937.—Ibid. **20**: 458, 1200, and 1523.

(5) Carrigan, T. (1936).—Proc. 7th Internat. Cong. Refrig., The Hague, IV: Sec. 3, 605.

(6) Ewell, A. W. (1930).—*Refrig, Engng.* **20**: 359.

(7) Ewell, A. W. (1932).—Ibid 23: 284.

(8) ———— (1933).—Ibid. 26: 68.

(9) ———— (1936).—Proc. 7th Internat. Cong. Refrig., The Hague, IV: Sec. 3, 203; and *Ice and Refrig.* 91: 295.

(10) ———— (1938).—*Food Res.* 3: 101.

(11) ———— (1940).—*Refrig. Engng.* 39: 237.

(12) Gorodetzkii, G. A. (1936).—*J. Appl. Chem., U.S.S.R.* 9: 353.

(13) Haines, R. B. (1934).—Ann. Rep. Food Invest. Bd., Lond., p. 44.

(14) ———— Ibid, 47.

(15) ———— (1935).—Ibid., p. 30.

(16) ———— (1937).—Spec. Rep. Food Invest. Bd., London, 45: 68.

(17) Heiss, R. (1937).—*Schr. Reichskurat Technik Landw.* 77: B.20.

(18) Hicks, E. W. (1935).—Ann. Rep. Food Invest. Bd., Lond., p. 19.

(19) Horne, G. A. (1936).—Inst. Amer. Meat Packers, 31st Convention, Proc. Operating Chem. Sections, p. 48.

(20) Kaess, G. (1936).—*Z. Ges. Kälte-Ind.* 43: 152; and Proc. 7th Internat. Cong. Refrig., The Hague, IV: Sec. 3, 193.

(21) ———— (1938).—*Chem.-Ztg.* 62: 365.

(22) ———— and Kiermeier, F. (1939).—*Z. Ges. Kälte-Ind.* 46: 185.

(23) Konstantinova-Schlezinger, *M.* (1935).—*Acta Physicochem., U.R.S.S.* 3: 435.

(24) Lea, C. H. (1938).—Spec. Rep. Food Invest. Br., Lond., p. 46.

(25) Lewis, W. L., and Yesair, J. (1928).—Inst. Amer. Meat Packers, Res. Lab. Bull., quoted by C. R. Moulton, "Meat through the Microscope," p. 202 (*Univ. of Chicago Press,* 1929).

(26) Mallman, W. L., and Churchill, E. S. (1946).—*Refrig. Engng.* 51: 523, and 52: 143.

(27) Milton, R. (1946).—*Food Trade Rev.* 16 (10): 2–3.

(28) Moran, T. (1935).—Ann. Rep. Food Invest. Bd., Lond., p. 40.

(29) Nevanas, S. V. (1938).—Brit. Pat., No. 492, 612.

(30) Edgar, J. L., and Paneth, F. A. (1941).—*J. Chem. Soc.* 1941: 511.

(31) Gluckauf, E., Heal, H. G., Martin, G. R., and Paneth, F. A. (1944).—Ibid. 1944: 1–4.

(32) Pennington, M. (1937/38).—*Brit. Assoc. Refrig. Proc.* 34 (2): 30.

(33) Regener, V. H. (1938).—*Met. Z.* 55: 459.

(34) Scott, W. J. (1936).—*J. Coun. Sci. Ind Res.* (Aust.) 9: 177.

(35) ———— (1937).—Ibid. 10: 338.

(36) ———— (1938).—Ibid. 11: 266.

(37) Stone, H. W., and Weiss, L. C. (1939).—*Ind. Eng. Chem.* (*Anal. Ed.*) 11: 220.

(38) Thorp, C. E. (1940).—Ibid. 12: 209.

(39) Usher, F. L., and Rao, B. S. (1917).—*J. Chem. Soc.* 111: 799.

(40) Willson, K. S. (1938).—*Ind. Eng. Chem.* (*Anal. Ed.*) 10: 279.

(41) Wolodkewitsch, N. (1936–37).—*Tätigkeit Kältetech, Inst. Karlsruhe,* p. 81.

An Electronic Device for Measuring Mechanical Phenomena

*By R. W. Muncey, B.E.E.**

Summary

This article describes the principle and operation of a new electronic device capable of measuring mechanical phenomena embracing both slow and rapid changes. Basically, the phenomenon to be measured causes a change of capacity in the tank circuit of an oscillator and the resulting frequency change is measured electronically. Photographic records are made from a cathode ray oscillograph.

1. Introduction

The device was developed in connection with a request by M.G.O. Branch, Design Division, Australian Military Forces, that the Section of Tribophysics, C.S.I.R., should design and build electronic equipment capable of measuring the buffer cylinder pressures of artillery during recoil. In order to reduce the effect of blast on the apparatus, it was necessary to have a minimum of components in close proximity to the gun, and to use a long connecting cable to the recorder. The circuit developed is sufficiently simple and convenient to warrant extensive use in the measurement of mechanical phenomena, particularly where central recording is desirable. The complete unit as supplied to Design Division is shown in Plate 4.

The equipment as designed is capable of:

(i) measuring mechanical phenomena, e.g. forces, pressures, displacements,

(ii) recording changes which may take place in the order of one millisecond,

(iii) being calibrated, using a static signal,

(iv) withstanding shock and vibration to the intensity of the blast waves from artillery,

(v) operating from an A.C. supply with variations of either voltage or frequency of the order of ± 5 per cent.

Since the development of the device outlined above, some details of similar equipment have been published (1, 2, 3, 4).

2. Consideration of Available Methods

Consideration was given in the first place to the usual methods for converting mechanical movements into electrical impulses. Broadly these fall into the following groups:

(*a*) change of resistance, e.g. carbon button, resistance strain gauge,

(*b*) electromagnetic induction, e.g. dynamic and ribbon microphone,

(*c*) piezo-electricity,

(*d*) capacity changes, e.g. charging currents, bridge circuits.

* Formerly an officer of the Division of Tribophysics, now with Building Materials Research.

After some consideration, it was felt that there were difficulties in all these methods. Electromagnetic induction and capacity charging currents involve integration and, together with piezo-electricity, require the use of dynamic calibration and amplifiers capable of very low-frequency response for the purpose under consideration. The former requirement is difficult to arrange, whilst the need for low-frequency amplification was considered to be undesirable in a field unit. This latter is also a difficulty in connection with the change of resistance method unless some form of high frequency A.C. bridge is adopted. This and the capacity bridge method, however, rely upon the amplification of the small difference between a fixed and a varying quantity and, from previous experience with these methods, it was realized that this feature would almost certainly give rise to trouble from microphonics.

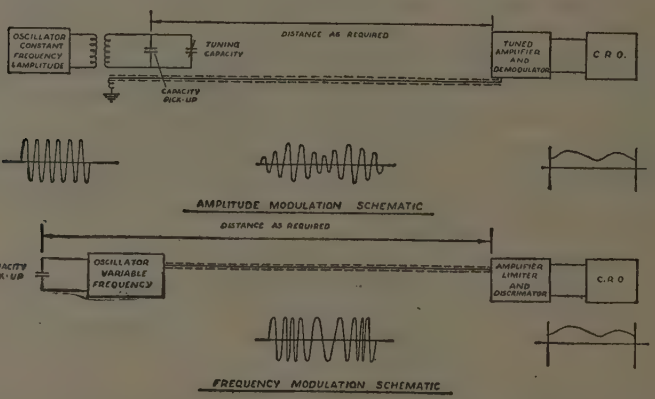


Fig. 1.—Block diagrams for amplitude and frequency modulation methods.

Some further possibilities were considered. In order to obviate the difficulty of low-frequency amplification, it seemed necessary to adopt a system of modulating a carrier wave, and for this two alternatives are available. One is to use amplitude modulation, varying the output amplitude of a high frequency oscillator as a function of the quantity to be measured, and the other is to use frequency modulation varying the frequency of the carrier wave. Block diagrams of these two possibilities are given in Fig. 1. Examination shows that in the former, an oscillator of good amplitude and frequency stability is required. Further, changes in amplitude resulting from microphonics will be directly reproduced in the recording apparatus, and consequently, difficulties from this source are probable. The method of frequency variation, however, would appear to be free from the requirement of high oscillator amplitude stability and from microphonic difficulties as a voltage limiter (constant amplitude) stage can precede the frequency demodulator.

3. Circuit Principles

It was decided to proceed with an experimental set-up using the principle of frequency modulation. The oscillator chosen should preferably have one plate of the capacity unit at earth potential and have zero D.C. voltage across the unit. This was accomplished using a tuned-grid feedback oscillator, whose oscillation frequency can be shown to be

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{C\,(L + lr/R)}}$$

where f is the frequency in cycles/sec.,
C is the resonating capacity in farads,
L is the resonating inductance in henries,
l is the inductance in the plate circuit in henries,
r is the load resistance in ohms,
and R is the plate resistance of the tube in ohms.

If, as is closely true, R and r remain constant for small changes in C, the frequency is inversely proportional to the square root of the capacity.

The capacity unit consists of two plates separated by a small distance which is varied by the phenomenon to be measured. The capacity between two plates of area A sq. in. separated a distance d in. by a dielectric of specific inductive capacity k is $0{\cdot}224\ kA/d\,\mu\mu$F. To determine the total resonating capacity, the capacity of the cable connecting the oscillator with the capacity unit must be added. If *this total capacity be* $500\,\mu\mu$F and the inductance $50\,\mu$H, the approximate oscillation frequency will be 1 megacycle/sec. A variation of $10\,\mu\mu$F in the capacity of the condenser unit will then give a frequency change of 10 kilocycles/sec. which can readily be measured. For a plate area of 1 sq. in. and a spacing of $0{\cdot}002$ in., such a variation requires a movement of $0{\cdot}0002$ in. of one condenser plate.

A signal of oscillator frequency is transmitted (by coaxial cable in the equipment constructed) to the amplifier-demodulator. The first stage of this is an amplitude-limited amplifier. This employs a conventional circuit run with a low screen voltage and a grid stopping resistor. The load on this amplifying stage has a resonant frequency close to that of the oscillator frequency, so that the impedance to harmonics in the plate current will be low and the output voltage will be almost purely fundamental, having an amplitude independent of the amplitude of the input signal. The relationship between the impedance of such a circuit and frequency is given in Fig. 2. If the incoming frequency may vary between f_1 and f_2, the tuned load of the amplifier is arranged so that these frequencies fall approximately as shown and, for a small change in frequency, a large change in impedance results. Now, as the amplifier output is effectively a constant current signal with a frequency equal to that of the input, the voltage across the tuned load will depend on the frequency. This voltage can be rectified and compared with a constant D.C. voltage. The difference is fed to the input of the push-pull stage which drives the cathode ray oscillograph. Early in the development of the

equipment it was found that a normal electronically-regulated supply was inclined to give a transient voltage change when the load current was suddenly changed and it was decided, therefore, to adopt a push-pull circuit to obtain a more nearly constant current drain.

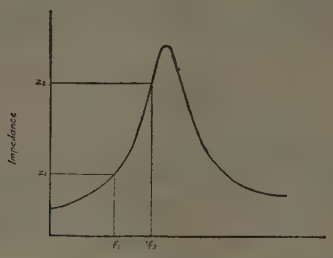


Fig. 2.—Response curve of tuned amplifier load.

The circuit as finally adopted differs from the circuits normally used in frequency modulation wherein extremely good linearity of output voltage to frequency change is sought. The added complication for this has been considered unnecessary in the present case in view of the fact that the change of capacity in the condenser unit is not linear with displacement and also that calibration from phenomenon to cathode ray tube (or to the film, in photographic recording) is both necessary and simple. Nevertheless, as will be shown later (see Fig. 3) the equipment provides a reasonable degree of linearity of capacity change to cathode ray tube deflection, and this is considered acceptable for the purpose required.

4. Description of the Apparatus

In the apparatus constructed, a 6V6GT type valve is used in the oscillator and is supplied with heater and high tension voltages via a four-way cable from the power supply of the amplifier-demodulator. The oscillator is constructed on a heavy steel plate and suspended in an airtight sump by rubber vibration dampeners as a precaution against the effects of the high blast pressures. An auxiliary winding on the oscillator coil, matched to the impedance of the coaxial cable, is used to transmit a signal of oscillation frequency to the demodulator which may be situated at any required distance from the oscillator sump. The coaxial cable is terminated by a matching transformer and load, and the voltage across the load is fed to the grid of the limiting amplifier, consisting of a single pentode (6AC7) stage, with a circuit tuned to the required frequency and inductively coupled as the plate load.

The voltage across this tuned circuit is compared with a constant D.C. voltage. One side of the tuned circuit is connected to the plates of a 6X5GT rectifier whose cathode is maintained at a fixed positive voltage. The other side of the tuned circuit is connected through a 0·2 megohm load to the cathode of the 6X5GT. The difference between

the D.C. and the rectified voltage appearing at the connection between tuned circuit and the load, is filtered and drives the final stage which consists of two 6V6GT tubes in push-pull. This stage is directly coupled to the *Y*-deflection plates of the cathode ray oscillograph.

It is intended in the apparatus constructed that the results should be photographed. To facilitate this, a 5LP5 cathode ray tube is used with 2,000 volts on the accelerating anode and 4,000 volts on the intensifier. These voltages are obtained from a power pack using 2X2 type tubes. The film is wrapped closely round a continuously revolving drum. When the phenomenon to be recorded occurs, the cathode ray beam will be " switched on " electronically, and after the elapse of a suitable period " switched off ", thus preventing the exposure of any section of the film more than once.

5. Performance

The frequency modulated measuring circuit outlined was tested at Gellibrand Proof Range during December 1944 and January 1945. The cable for connection to the capacity unit was firmly attached to the barrel of a two pounder Mk.X gun and the output of the demodulator during firing was observed on a cathode ray oscillograph. The maximum output voltage was about eight volts. This would cause a movement of approximately one-tenth of an inch of the spot of the cathode ray tube of this equipment, i.e. about 2 per cent. of full-scale deflection. Later the oscillator was placed on the ground 5 feet below and 5 feet in front of the muzzle of a 4·7 in. Mk. XIIb gun firing point blank, and the output again observed on the cathode ray oscillograph. The output voltage in this case was about five volts, approximately 1 per cent. of the full-scale deflection of the cathode ray oscillograph. It is to be expected, therefore, that microphonics, even in severe conditions, will be limited to 5 per cent. of full-scale deflection, an amount which should not produce undue interference.

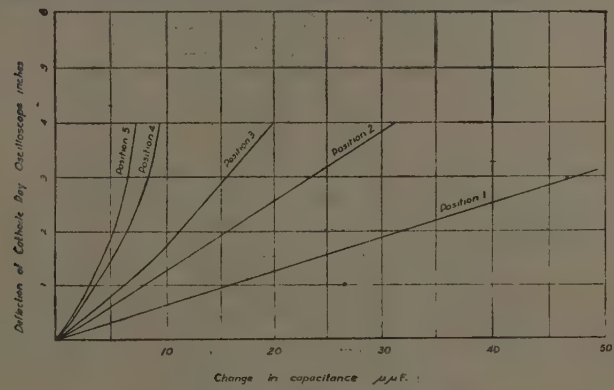


Fig. 3.—Sensitivity curves.

The equipment has a built-in, electronically regulated power pack which delivers a constant high tension voltage from a variable input supply. However, some drift is caused due to changes in heater

voltages. Over a period of several hours (after warming up) the drift was found to be about 20 per cent. of full-scale deflection. This can be observed on the monitoring meter and adjusted by a slight alteration of the tuning setting to restore the meter reading. Should this drift be considered excessive, however, a constant voltage transformer in the input line may be used to maintain the heater voltage more nearly constant.

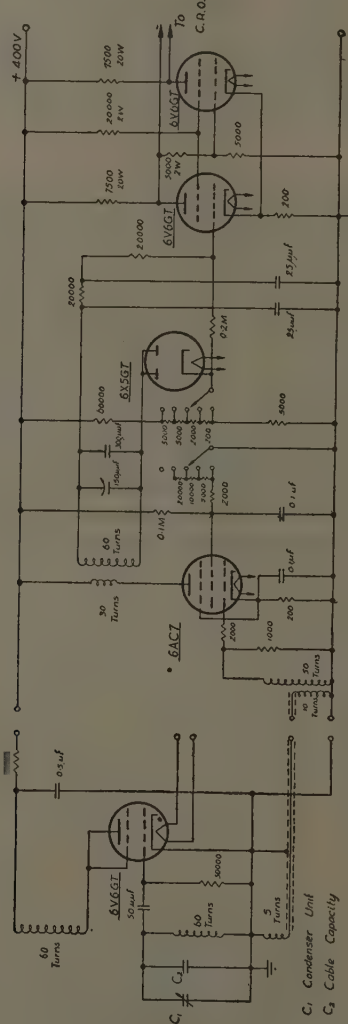


FIG. 4.—Circuit diagram of oscillat or and amplifier-demodulator

The curves of Fig. 3 indicate the sensitivity and linearity of capacity change to the spot deflection available. The connecting cable to the capacity unit had a total capacity of 500$\mu\mu$F. It has been considered desirable to use a cable having 7/·044 copper strands as central conductor, $\frac{3}{8}$-in. diam. tinned-copper braid, solid rubber dielectric and rubber covering, on account of its reported non-microphonic properties.

6. Conclusion

Field and laboratory testing of this equipment indicate that the initial requirements of Design Division will be fulfilled. The equipment is capable of measuring forces, pressures and other phenomena by converting them to a small movement of one plate of a condenser. Extremely rapid changes may be recorded, and in addition, the equipment is insensitive to microphonics and can be calibrated statically.

As yet little practical experience has been gained in the long term stability and operational functioning of the equipment. The chief difficulties in obtaining high accuracy appear to be in maintaining the constancy of the heater currents over long periods and of the atmospheric conditions around the tuned circuits (oscillator and amplifier load). Effectively, the measurement is based upon a comparison of the impedance properties of these circuits.

On the other hand, the following advantages are already apparent:

(i) measurement of mechanical phenomena involving rapid variations,

(ii) ease of calibration,

(iii) simplicity of measurement for both slow and rapid changes,

(iv) absence of electronic overload troubles,

(v) possibility of extensive use since most mechanical phenomena can be transformed to a relative movement between two parallel plates,

(vi) insensitivity to vibration and microphonics,

(vii) ease of measuring at inaccessible places.

7. References

(1) Bradshaw, E. (1945).—A change of capacitance method for the measurement of mechanical displacements. *J. Sci. Instr.* 22: p. 112-5.

(2) Heald, R. H. (1945).—A description of frequency modulated electronic circuits for use with capacity strain gauges. Royal Aircraft Est. Farnborough, Technical Note Vib. 9.

(3) Miessner, B. F. (1944).—Frequency modulated phonograph pick-up. *Electronics* 17: 132-3.

(4) Dayton, R. W., and Foley, G. M. (1946).—Capacitative micrometer. Ibid. 19: 106–11.

Studies in Cement-Aggregate Reaction

VIII. The Expansions of Composite Mortar Bars

*By H. E. Vivian, B.Sc.Agr.**

Summary

Composite bars consisting of various numbers of sections of different mortars (half reactive and half non-reactive), expand by amounts which, when calculated on the total length of reacted mortar, are higher than those of uniform bars. It is suggested that larger amounts of water are available in composite bars and that their higher expansions depend largely on these.

1. Introduction

In an earlier paper of this series† it was shown that some composite mortar bars made of various combinations of high and low-alkali cements with reactive and non-reactive aggregates expanded to a greater degree than uniform bars made from high-alkali cement and reactive aggregate. The differences between composite and uniform bars became very noticeable when expansions were calculated on the length of reacted mortar in the bar rather than on the effective length (10 inches) of the test piece. It was suggested that the high expansions of composite bars were caused by increments in the amounts of available alkalis or water or both, which were derived from adjoining sections containing non-reacted aggregate.

The present investigation was designed to test this hypothesis for, if the hypothesis be well founded, the effects of the additional amounts of alkalis and water should become more apparent as the number of sections of each type of mortar in composite bars is increased. Detailed discussion in this paper is confined to the results obtained from one reactive aggregate similar results have been obtained with another aggregate containing as its reactive component opaline chert (28038) from California.

2. Materials and Method

Two different cements were used. These were high-alkali cement (H) containing 0·98 per cent. total alkalis, and low-alkali cement (L) containing 0·15 per cent. total alkalis. Chemical analyses of these cements are shown in Table 1. It should be noted that neither cement was used in the previous work on composite mortar bars†.

TABLE 1.—CHEMICAL ANALYSES OF CEMENTS

Cement	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on Ignition
H ..	22·14	2·38	4·94	64·12	1·08	1·84	0·45	0·81	1·88
L ..	23·56	5·17	4·25	61·64	0·61	1·57	0·00	0·22	2·89

* An officer of the Division of Industrial Chemistry.

† Vivian, H. E. (1947).—Coun. Sci. Ind. Res. (Aust.) Bull. No. 229, pp. 47-54.

The reactive aggregate (R) used was a mixture of 5 per cent. opaline rock (V.17) from east Gippsland, Australia, crushed and sieved to − 18 + 52 B.S.S. mesh, plus 95 per cent. Leighton Buzzard sand. The non-reactive aggregate (NR) was Leighton Buzzard sand.

The water/cement/aggregate ratio, 0·5:1:2 by weight, was the same for all mortars. Bars consisting of alternate sections of mortars were made as previously described (Vivian loc. cit.). After curing for twenty hours in a moist cabinet the test-bars were removed from the moulds, measured, and stored in moist air in sealed containers kept at room temperature.

3. Plan of Experiment

Composite bars consisted of alternate sections of the following mortars:

(i) Cement H + aggregate R and cement L + aggregate NR.

(ii) Cement H + aggregate R and cement H + aggregate NR.

(iii) Cement H + aggregate NR and cement L + aggregate R.

(iv) Cement L + aggregate R and cement L + aggregate NR.

A plan of one set of test bars ((i) above) is shown in Fig. 1. The five types of composite mortar bars in each set differed only in the number of sections of each mortar per bar.

Control bars consisting of one uniform mortar (some of cement H + aggregate R; others of cement L + aggregate R) were made and stored under the same conditions as composite bars.

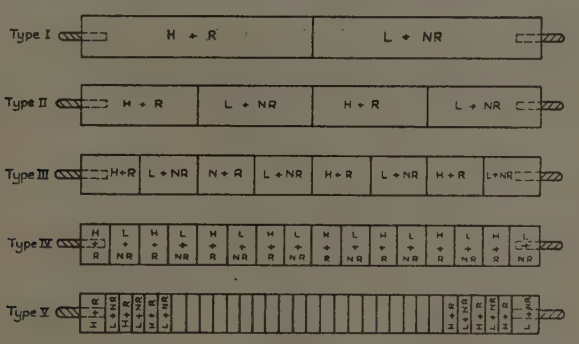


FIG. 1.—Plan of composite test bars showing the relations of the two mortars ((i) cement H + aggregate R and cement L + aggregate NR). (One quarter natural size.)

Type I.—One section of each mortar and one interface.

Type II.—Two sections of each mortar and three interfaces.

Type III.—Four sections of each mortar and seven interfaces.

Type IV.—Eight sections of each mortar and fifteen interfaces.

Type V.—Sixteen sections of each mortar and thirty-one interfaces.

4. Results

The expansions of test bars containing opaline rock (V.17) are shown as follows:

(i) In Table 2 are the expansions produced by uniform mortar bars. These expansion results are also shown graphically in Fig. 2.

(ii) Table 3 shows the measured expansions exhibited by composite bars. These figures are included to show the high expansions of composite bars which contain numerous sections.

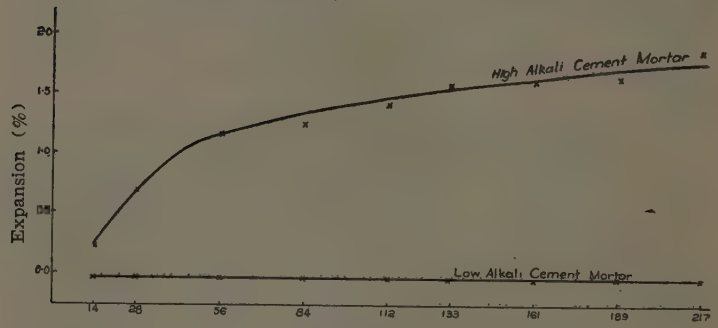


FIG. 2.—Expansions of uniform mortar bars.

It should be noted that all the bars in Tables 2 and 3 were made within a period of four days. The expansions of similar mortar bars made at widely separated times differed considerably among themselves. Such expansion differences probably depend on differences in the mean storage temperatures especially during the initial critical

TABLE 2.—THE PERCENTAGE EXPANSIONS OF UNIFORM TEST BARS

Time after Fabrication (days)	Cement H + Aggregate R	Cement L + Aggregate R
7	+ 0·036	— 0·008
14	0·243	— 0·010
21	0·483	— 0·010
28	0·699	— 0·013
35	0·810	— 0·012
42	0·933	— 0·014
49	1·055	— 0·013
56	1·181	— 0·014
70	1·204	— 0·016
84	1·255	— 0·017
98	1·339	— 0·017
112	1·443	— 0·022
133	1·604	— 0·023
161	1·641	— 0·024
189	1·662	— 0·015
217	1·895	— 0·011

stages of reaction between alkalis and opal. For similar series of bars made at different times the relative order of expansions is reproducible but not the actual magnitude of the individual results.

TABLE 3.—THE PERCENTAGE EXPANSIONS OF COMPOSITE TEST BARS

Composition of Bars	Time after Fabrication (days)	Number of Sections of Each Mortar				
		1	2	4	8	16
(i) Sections of (H + R) and (L + NR)	7	+ 0·032	+ 0·030	+ 0·014	+ 0·018	+ 0·011
	14	0·140	0·125	0·105	0·084	0·045
	21	0·273	0·273	0·236	0·317	0·265
	28	0·390	0·421	0·404	0·595	0·636
	35	0·429	0·478	0·486	0·726	0·786
	42	0·530	0·562	0·574	0·887	0·980
	49	0·587	0·640	0·714	1·081	1·176
	56	0·647	0·699	0·767	1·101	1·253
	70	0·672	0·744	0·858	1·237	1·423
	84	0·709	0·809	0·940	1·393	1·652
	98	0·787	0·880	1·003	1·517	1·785
	112	0·821	0·931	1·110	1·680	1·941
	133	0·878	1·011	1·211	1·837	2·183
	161	0·895	1·045	1·227	1·851	2·210
	189	0·971	1·085	1·250	1·958	2·375
	217	1·037	1·197	1·401	2·088	..
ii) Sections of (H + R) and (H + NR)	7	+ 0·007	+ 0·008	+ 0·010	+ 0·008	+ 0·007
	14	0·096	0·100	0·101	0·133	0·130
	21	0·204	0·217	0·228	0·282	0·328
	28	0·353	0·389	0·423	0·502	0·493
	35	0·445	0·493	0·548	0·664	0·749
	42	0·536	0·586	0·660	0·811	0·902
	49	0·566	0·659	0·750	0·935	1·027
	56	0·635	0·719	0·832	1·053	1·128
	70	0·728	0·799	0·930	1·171	1·269
	84	0·763	0·904	1·057	1·310	1·397
	98	0·805	0·920	1·081	1·401	1·490
	112	0·819	0·929	1·101	1·421	1·514
	133	0·833	0·950	1·144	1·534	1·637
	161	1·029	1·116	1·310	1·714	1·753
	189	1·018	1·118	1·304	1·710	1·751
	217	1·031	1·124	1·321	1·728	1·779
(iii) Sections of (H + NR) and (L + R)	7	+ 0·001	— 0·005	— 0·002	— 0·005	+ 0·001
	14	0·003	— 0·004	— 0·005	— 0·004	0·004
	21	0·003	— 0·004	— 0·005	— 0·002	0·015
	28	0·002	— 0·004	— 0·006	+ 0·029	0·114
	35	0·003	+ 0·003	+ 0·011	0·068	0·187
	42	0·003	0·010	0·033	0·126	0·281
	49	0·005	0·016	0·065	0·169	0·356
	56	0·015	0·031	0·103	0·245	0·473
	70	0·017	0·049	0·182	0·398	0·710
	84	0·029	0·082	0·250	0·564	0·942
	98	0·032	0·097	0·290	0·652	1·002
	112	0·031	0·105	0·323	0·717	1·105
	133	0·034	0·124	0·368	0·820	1·253
	161	0·035	0·136	0·412	0·876	1·312
	189	0·060	0·153	0·434	0·967	1·443
	217	0·048	0·161	0·462	1·030	1·499

TABLE 3.—THE PERCENTAGE EXPANSIONS OF COMPOSITE TEST BARS—*continued*

Composition of Bars	Time after Fabrication (days)	Number of Sections of Each Mortar				
		1	2	4	8	16
(iv) Sections of (L + R) and (L + NR)	7	+ 0·001	+ 0·004	— 0·002	— 0·003	+ 0·004
	14	— 0·001	— 0·001	..	..	0·001
	21	+ 0·002	+ 0·001	+ 0·003	+ 0·003	0·003
	28	0·001	— 0·001	0·004	0·003	0·001
	35	0·003	± 0·000	0·007	0·006	0·003
	42	— 0·002	— 0·002	— 0·001	— 0·002	± 0·000
	49	± 0·000	+ 0·003	+ 0·002	+ 0·001	+ 0·002
	56	+ 0·001	0·002	0·001	— 0·003	0·003
	70	0·005	0·001	± 0·000	± 0·000	0·003
	84	0·001	0·001	— 0·001	— 0·004	0·002
	98	— 0·001	— 0·001	± 0·000	— 0·006	0·001
	112	— 0·003	— 0·003	— 0·004	— 0·010	± 0·000
	133	± 0·000	— 0·002	— 0·003	— 0·013	± 0·000
	161	+ 0·002	± 0·000	± 0·000	— 0·020	+ 0·005
	189	0·011	+ 0·007	+ 0·016	— 0·011	0·012
	217	± 0·000	— 0·003	— 0·004	— 0·004	0·003

Conclusions

(*a*) The expansions of composite bars increased with number of sections of each mortar (i.e. according to the number of interfaces). This was shown most clearly by the expansions of composite bars containing sections of (H + NR) and (L +R) mortars.

(*b*) The measured expansions of composite bars containing eight and sixteen sections of each mortar ((H + R) and (L + NR); (H + R)) and H + NR)) were greater than the expansions of uniform (H + R) bars even though they contained only 5 inches (approximately) of reacted mortar.

(*c*) Although the actual expansions of composite bars containing 1, 2, and 4 sections of the above mortars were less than those of uniform (H + R) bars the expansions of reactive aggregate mortar in the former were greater than the expansion of the reactive aggregate mortar in the latter. This will be examined later in this paper.

(*d*) Composite bars containing sections of (H + NR) and (L + R) mortars expanded even though the reactive aggregate was associated with the low alkali cement. This indicates that alkalis moved from the (H + R) to the (L + NR) sections.

(*e*) Composite bars containing sections of (L +R) and (L + NR) mortars did not expand abnormally.

(*f*) Uniform (H + R) bars expanded abnormally but (L + R) bars showed no undue expansion.

Observations

(*a*) Sections which contained (H + R) mortar showed numerous wet spots on their surfaces.

(*b*) Sections of (H + NR) and of (L + NR) mortars showed no wet spots.

(*c*) Sections of (L + R) mortar showed numerous wet spots near the contacts with sections of (H + NR) mortar. Wet spots were not apparent elsewhere in these sections.

(*d*) Composite bars containing sections of (L + R) and (L + NR) mortars had a few small spots on the surfaces of (L + R) sections.

(*e*) Cracks were observed in all composite bars except those consisting of sections of (L + R) and (L + NR) mortars. Cracks near interfaces were generally transverse whereas those in the central parts of sections were randomly distributed. Transverse cracking was so severe that most composite mortar bars collapsed within nine months of fabrication.

(*f*) Cracks were observed only in those uniform bars which contained (H + R) mortar. The occurrence and direction of these cracks were completely randomized.

5. Calculated Expansions of Composite Bars

Since the lengths of the various sections could not be controlled accurately during fabrication, the individual lengths of mortar which had reacted in each bar were measured at 161 days. The measured expansions from Table 3 when multiplied by a factor $10/l$ (where l = sum of all the measured lengths of reacted mortar per bar) gave the calculated expansions shown in Table 4.

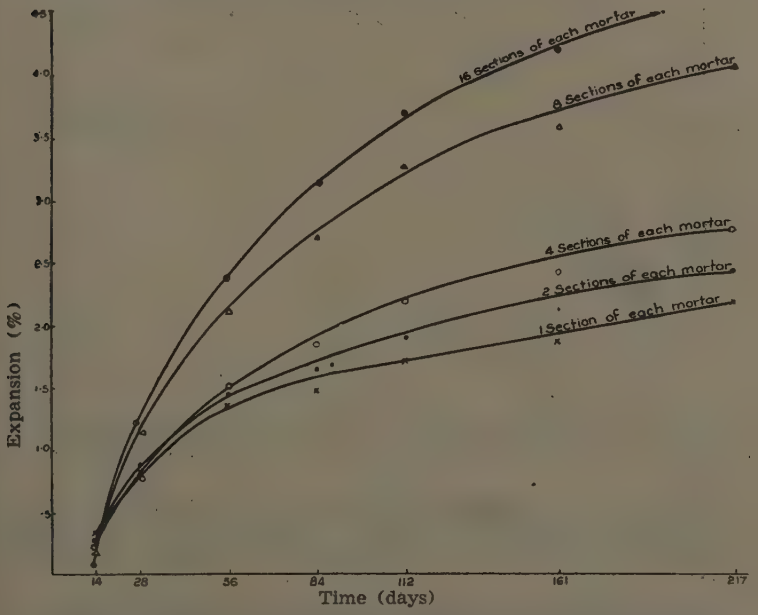


FIG. 3.—Calculated expansions of composite mortar bars containing section of cement H ÷ aggregate R, and cement L + aggregate N.R.

Calculated expansions are subject to errors arising in:

(i) routine expansion measurements,

(ii) measuring the lengths of reacted mortar in each bar,

(iii) the neglect of the effect of cracks on the expanding reaction product,

(iv) the assumption that expansion is constant over the entire length of a given mortar section. There are indications that expansion is higher near the contacts with adjacent sections than elsewhere. This applies mainly to bars containing (H + R) sections and to a less extent to bars containing (H + NR) and (L + R) sections,

(v) in neglecting variations in the selected length of reacted mortar in bars containing (H + NR) and (L + R) sections. Only one factor was used for the calculated expansions although the length of reacted mortar had been increasing slowly with time.

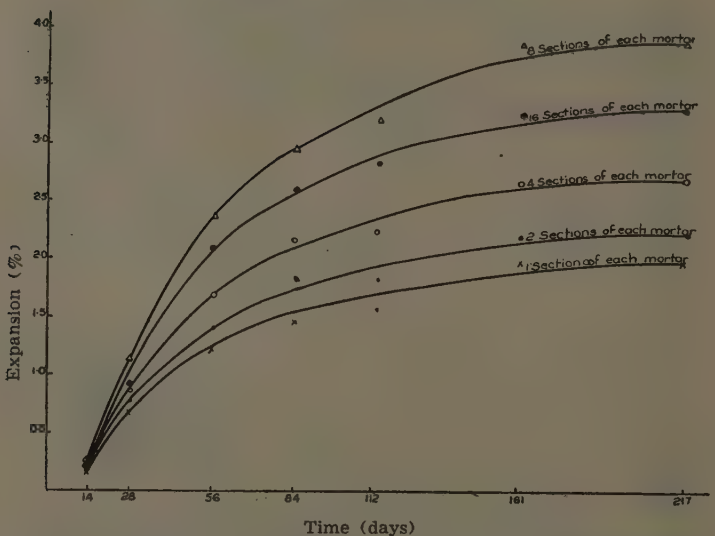

Expansion (%)
Time (days)
8 Sections of each mortar
16 Sections of each mortar
4 Sections of each mortar
2 Sections of each mortar
1 Section of each mortar

FIG. 4.—Calculated expansions of composite mortar bars containing sections of cement H + aggregate R, and cement H + aggregate NR.

Errors (i) and (ii) affect all mortars but are of greater significance in low- than in high-expanding mortars; (iii) affects all mortars which expand and crack, (iv) and (v) affect only the test pieces mentioned above.

The calculated expansions of composite bars, recorded in Table 4, are shown graphically in Figs. 3, 4, and 5. These graphs should be compared with those of uniform bars shown in Fig. 2.

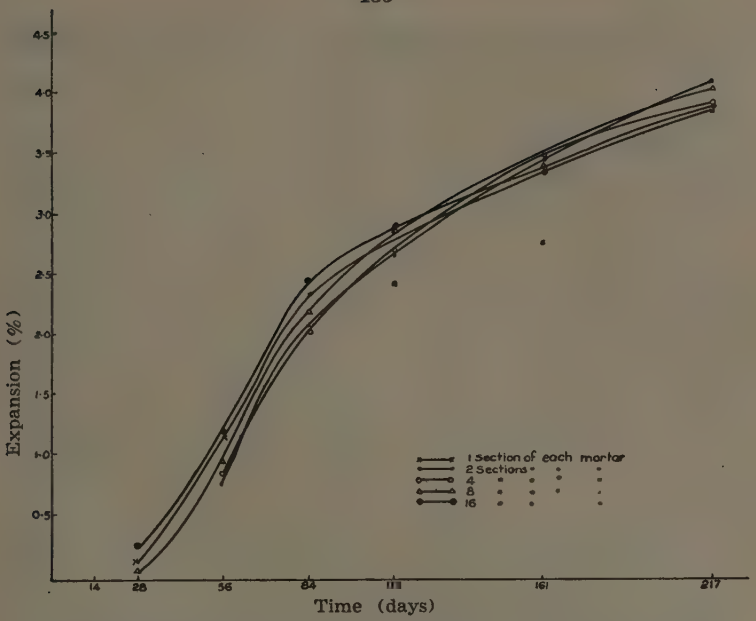


FIG. 5.—Calculated expansions of composite mortar bars containing sections of cement H + aggregate NR, and cement L + aggregate R.

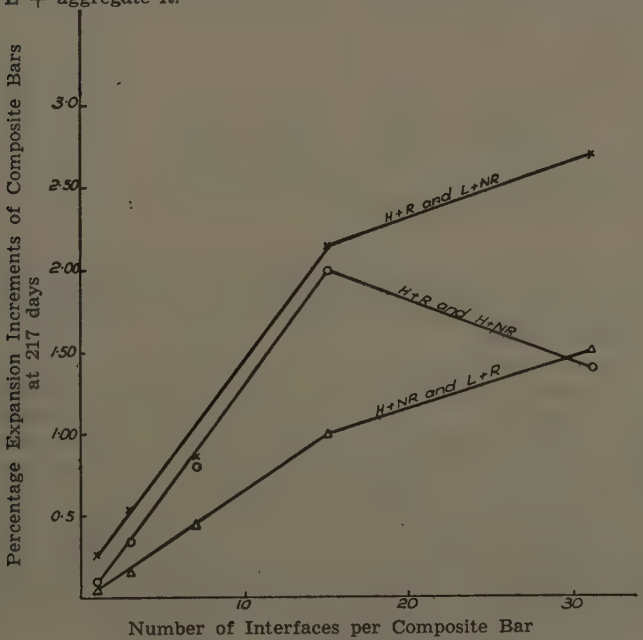


FIG. 6.—The effect of number of interfaces on the expansion increments of composite mortar bars.

TABLE 4.—THE CALCULATED PERCENTAGE EXPANSIONS OF COMPOSITE BARS.

Composition of Bars	Time after Fabrication (days)	Number of Sections of Each Mortar per Bar				
		1	2	4	8	16
		2·09*	2·04*	1·98*	1·94*	1·90*
(i) Sections of (H + R) and (L + NR)	14	0·29	0·26	0·21	0·16	0·09
	28	0·82	0·86	0·80	1·15	1·21
	56	1·35	1·43	1·52	2·14	2·38
	84	1·48	1·65	1·86	2·70	3·14
	112	1·72	1·90	2·20	3·26	3·69
	161	1·87	2·13	2·43	3·59	4·20
	217	2·17	2·44	2·77	4·05	..
		1·94*	1·99*	2·05*	2·25*	1·86*
(ii) Sections of (H + R) and (H + NR)	14	0·19	0·20	0·21	0·30	0·27
	28	0·69	0·77	0·87	1·13	0·92
	56	1·23	1·43	1·71	2·37	2·10
	84	1·48	1·80	2·17	2·95	2·60
	112	1·59	1·85	2·26	3·20	2·82
	161	2·00	2·22	2·69	3·86	3·26
	217	2·00	2·24	2·71	3·89	3·31
		80·00*	25·60*	8.44*	3·95*	2·62*
(iii) Sections of (H + NR) and (L + R)	14	..	..	..	..	..
	28	0·16	..	..	0·11	0·30
	56	1·20	0·79	0·87	0·97	1·24
	84	2·32	2·10	2·11	2·23	2·47
	112	2·48	2·69	2·73	2·83	2·89
	161	2·80	3·48	3·48	3·46	3·44
	217	3·84	4·12	3·90	4·07	3·93

* Factors used for converting actual to calculated expansions.

Conclusions

(*a*) Expansions calculated on the total length of reacted mortar in composite bars were higher than those of uniform bars. This refers to all parts of Table 4.

(*b*) The expansions of composite bars containing sections of (H + R) and (L + NR) (part (i)) and those containing sections of (H + R) and (H + NR) (part (ii)) indicated that (1) additional amounts of water increased the expansion of reacted aggregate particles and (2) the expansion of any given section of reactive aggregate mortar varied along its length.

Although expansion generally increased as the number of interfaces increased it was also influenced by other factors. This is shown in Fig. 6 where the differences in expansion at 217 days between composite bars (part (i) and (ii)) and uniform (H + R) bars from Table 2 are plotted against number of interfaces. The differences

between the actual expansions of composite bars (H + NR) and (L + R) (part (iii), Table 3) and uniform (L + R) bars plotted against number of interfaces are also shown in Fig. 6.

The widely different expansions of composite bars containing sixteen sections each of (H + R) and (L + NR) mortars and of those containing the same number of (H + R) and (H + NR) mortar sections suggest that increased amounts of available alkalis may affect the expansion of reactive aggregate. Further comment on these effects will be made later in this paper.

(*c*) The expansions of (H + NR) and (L + R) composite bars (part (iii)) were almost independent of the number of sections or interfaces.

(*d*) No calculated expansions for composite bars consisting of (L + R) and (L + NR) mortar sections have been included since it was impossible to determine the length of reacted mortar. Furthermore at 217 days their measured expansions were very low and probably contained large errors due to unavoidable variations in length measurements.

These conclusions need some further comment. Comparisons should not be made between composite bars containing (H + R) sections (parts (i) and (ii), Table 4) and those containing (L + R) sections (part (iii), Table 4). Increase in expansion of (H + R) and (L + NR); and (H + R) and (H + NR) composite bars should depend on the number of interfaces or sections. Any additional effect on expansion caused by the (L + NR); or (H + NR) sections is superimposed on the ordinary expansion of the (H + R) sections. The additional effect of water and alkalis on the (H + R) sections increases the total length of reacted mortar only by the small amount which it expands.

The calculated expansions of (L + R) and (H + NR) composite bars should be independent of the number of interfaces or sections and of the total length of reacted mortar in each bar. It should be noted that the length of reacted mortar in these bars is less than the total length of potentially reactive mortar, i.e. (L + R) mortar. Measured expansion depends on the number of interfaces because it is only at interfaces that reaction can occur. The length of reacted mortar increases as the number of interfaces increases and the factor used for obtaining the calculated expansions should vary inversely as the number of interfaces. The calculated expansions of these bars should therefore be approximately uniform.

6. Discussion

Although it is difficult to differentiate between the separate effects of water and alkalis it seems certain, from the compositions of the different sets of bars, that much of the increased expansion is caused by additional amounts of available water. Much of the discussion which follows concerns the behaviour of water in composite bars containing (H + R) and (L + NR) mortar sections. This part of the discussion could be applied to any mortar containing reacting aggregate.

The increased amounts of available water could be obtained partly from the non-reactive mortar sections and partly from the storage atmosphere or entirely from either. Evidence has been obtained from other composite bars which shows that the increased amount of available water is derived from non-reactive mortar sections. These bars, which were completely coated with paraffin wax (m.p. 50°C.) to prevent interchange of available water between the mortar and the storage atmosphere, gave expansions of the same order as uncoated bars. Water vapour absorbed from the storage atmosphere should have a negligible effect on mortar expansion because over short intervals of time it seems to be absorbed only by reacted particles situated close to the external surfaces of the bars. These particles which appear to form sols do not cause severe cracking or expansion. Over a long period of time absorption of water vapour may increase mortar expansion although other factors may reduce its effect.

The following reasons indicate further that the measured expansions of composite bars are increased by water absorbed mainly from the non-reactive mortar sections. (1) As all bars were stored under the same conditions it is presumed that all should have been uniformly affected by any water vapour absorbed from the atmosphere and (2) expansion generally increases as the number of sections of each type of mortar is increased.

In addition to the deduction that expansion increases depend on water which moves from non-reactive to reactive aggregate mortar sections it seems necessary, in order to account for the high expansions of composite bars, to assume that most of the water is absorbed as vapour and not as liquid. If a large amount of free water were in contact with the reacted aggregate, the material at the surfaces of the reacted particles would be dispersed rapidly and continuously to form a sol or solution. Expansion under these conditions would be decreased rather than increased.

The differences between the expansions of composite and uniform bars suggest that expansion of the latter is limited by the smaller amount of available water. It is also probable that the rate at which water is absorbed by the reacted aggregate affects the magnitude of the final measured expansion.

The actual movement of water in mortar is probably influenced by a number of factors. The most important is the low water vapour pressure exerted by reacted aggregate particles which causes water to move from the solution in the hydrated cement to the reacted particles. It is possible that water may be absorbed partly from the liquid phase and partly from the vapour phase. A factor which may retard the movement of water vapour is the difference in alkali concentrations in the solutions in high- and low-alkali mortar sections. Any effect caused by this is probably small and decreases with time.

Movement of alkalis from the solution in the hydrated cement to the reactive aggregate particles is known to occur (Vivian, loc. cit.). It is also certain that some alkalis diffuse from high to low-alkali cement-containing sections in the composite bars described in this paper. This is most important in bars consisting of (H + NR) and (L + R) mortar sections since expansion depends on alkali movement and consequent aggregate attack. In bars containing (H + R) and

(L + NR) mortar sections this movement of alkalis is not so important since it would decrease only slightly the amount available for reaction. Excessively large amounts of alkalis (especially in the presence of large amounts of water) reduce expansion by converting the reaction product rapidly from the gel to the sol state. This should only apply to bars containing sections of (H + R) and (H + NR) mortars and should become more apparent as the number of sections is increased.

As indicated earlier in this paper the number of interfaces or the number of sections of each type of mortar influences expansion because the amount of reactive aggregate mortar affected by water or by alkali diffusion or by both increases as the number of interfaces increases. In addition as the number of interfaces increases the length of each individual section decreases. The general effect of increasing the number of sections of each mortar above a certain maximum is to reduce the increase in expansion (see Fig. 6). The reasons for this are different for each type of composite bar and are now indicated briefly. Expansion of composite bars containing (H + R) and (L + NR) mortars is limited by insufficient water; expansion of (H + NR) and (L + R) composite bars is limited by insufficient alkalis and water, and expansion of (H + R) and H + NR) composite bars is limited by insufficient water and also reduced by the high amount of alkalis available for aggregate reaction. From this it can be seen that, although the amount of mortar that can be affected by additional alkalis and water increases as the number of interfaces is increased, the amount of alkalis and water available at each interface tends to decrease on account of the decrease in length of the sections.

The expansion of any mortar seems to be affected by two limiting factors. The rate at which the reactive aggregate is attacked probably constitutes the initial limiting factor. As the rate of reaction between alkalis and reactive aggregate decreases the rate of water absorption becomes more important and as the reaction rate of alkalis and aggregate approaches zero the rate of water absorption probably becomes the main limiting factor. It should be noted however that, on account of changes which occur in the mortar and in the expansive properties of reacted aggregate as it absorbs water, other factors which can modify expansion become operative. Some of these will be discussed in later papers.

Transverse cracks near interfaces may modify the expansion of composite bars. These cracks could prevent the continued diffusion of alkalis from one mortar section to another. Although water vapour could move across these cracks its effect on mortar expansion would be minimized especially if it were absorbed by reacted particles situated on or near their surfaces. This probably occurs in all mortars which undergo high expansion and extensive cracking.

In conclusion it should be stressed that the amount of water in mortar, available for absorption by reacted aggregate particles, is an important variable which directly affects the swelling of aggregate particles and thereby indirectly affects mortar expansion. Water should therefore be regarded equally with reactive component in the aggregate and with alkalis as essential for mortar expansion.

An Experimental Kiln for Ceramic Ware

*By H. V. Hueber, Dr. Phil.**

Summary

An experimental kiln suitable for burning 70 to 75 common bricks or an equivalent capacity of other ceramic products, under normal plant conditions, is described. The kiln may be fired with coal, oil, or wood. Minor variations in construction, dependent upon the fuel used, are discussed.

1. Introduction

The final decision, as to the suitability of any ceramic raw material for a particular purpose, cannot be given without an actual production test, carried out not only on small trial samples, but also on full-scale products of the type for which the material will be used.

Such production tests on full-scale samples should never be omitted, particularly where tests are intended as the basis for a plant or works project. However, in practice, full-scale reliable tests are difficult to obtain. Laboratory kilns are generally not designed to take full-scale samples and, moreover, seldom reproduce actual plant conditions. Most of the laboratory kilns in use at the present time are either electrically heated or fired with oil, or gas, under pressure. In electrically heated kilns the material is heated under completely artificial conditions, i.e. in ordinary air, whereas, in practice, the material is in contact with the gaseous combustion products from the fuel, which influence the composition and final appearance of the product to a very marked degree. Where blast burners using oil, or gas, are employed, the heat produced is usually far too intense for the normal initial steaming (water-smoking) of the ware and, in consequence, full-sized samples requiring a very slow steaming rate cannot be used.

Full-scale testing is consequently frequently carried out in an operating plant; however, these tests are not always reliable because the working conditions in such plants may have been developed and adapted for quite a different raw material.

In order to meet the need for a simple appliance in investigational work, a small kiln has been designed possessing definite advantages over other laboratory kilns in use to-day. It is eminently suitable both for use in a research laboratory and as a testing kiln for works control. The kiln has the further advantage that it is cheap to construct, i.e. less than £40 under present conditions.

2. Construction of The Kiln

The kiln is a down-draft type, with an actual setting space of 7 cubic feet, measuring 20 in. by 30 in. by 20 in. It takes 70 to 75 common bricks or an equivalent setting of other ceramic products. It may be fired with oil, coal, or wood. Each type of fuel requires a specific space for developing the flame before the fire enters the burning chamber. Accordingly, slight modifications are necessary in the

* An officer of Building Materials Research.

design of the furnace, and in the size of the free space between the burning surface and the burning chamber. Elevation and section details of the kiln for the three types of fuel are illustrated in Figs. 1 to 3; views of the oil-fired kiln in operation in the Building Materials Research Laboratory at Highett, are shown in Plates 5 and 6.

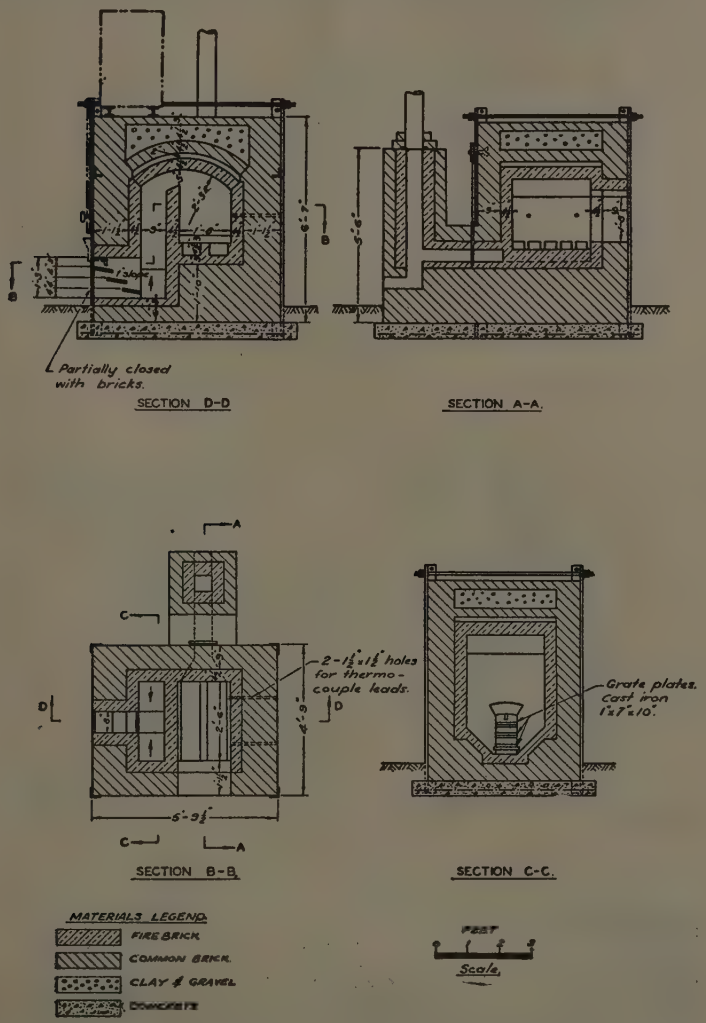


FIG. 1.—Experimental kiln, oil-fired. The lining shown is for medium temperatures, but for high or low temperatures the linings necessary would be those shown in Figs. 2 and 3 respectively.

The kiln, apart from the firebrick lining of the burning chamber, is normally built of common bricks* on a concrete or other suitable foundation. For the lining of the furnace itself common bricks may be used where a maximum temperature of only 1150° C. (2100° F.) is required. For higher temperatures up to about 1300° C. (2400° F.) a furnace lining of firebricks (of medium quality) is necessary but

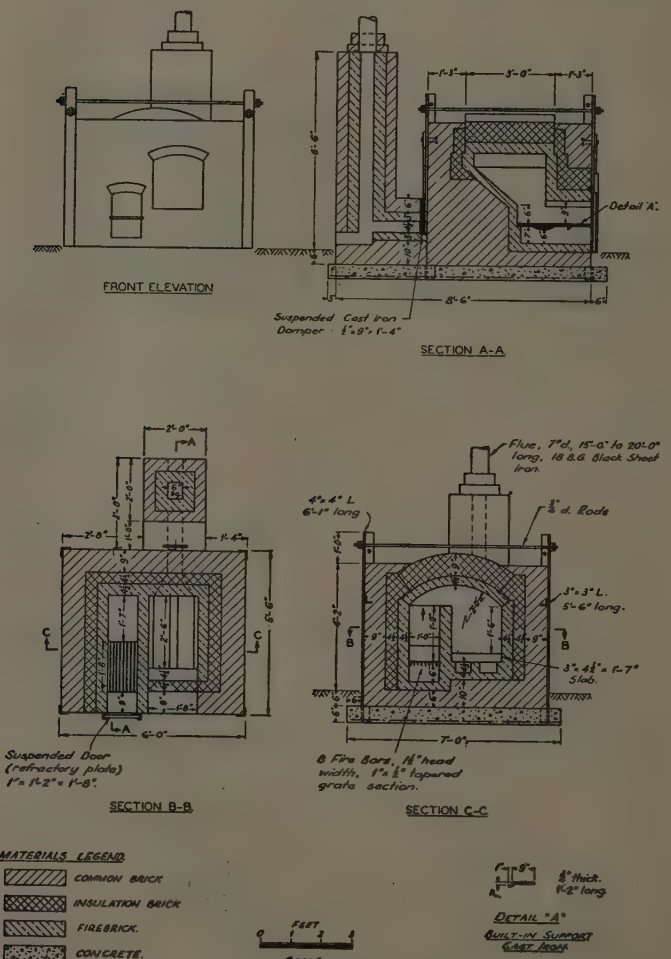


FIG. 2.—Experimental kiln, coal-fired. The lining shown is for high temperature work but this lining may be interchanged with those shown in Figs. 1 and 3 where medium or low temperatures only are required.

* See footnote on opposite page.

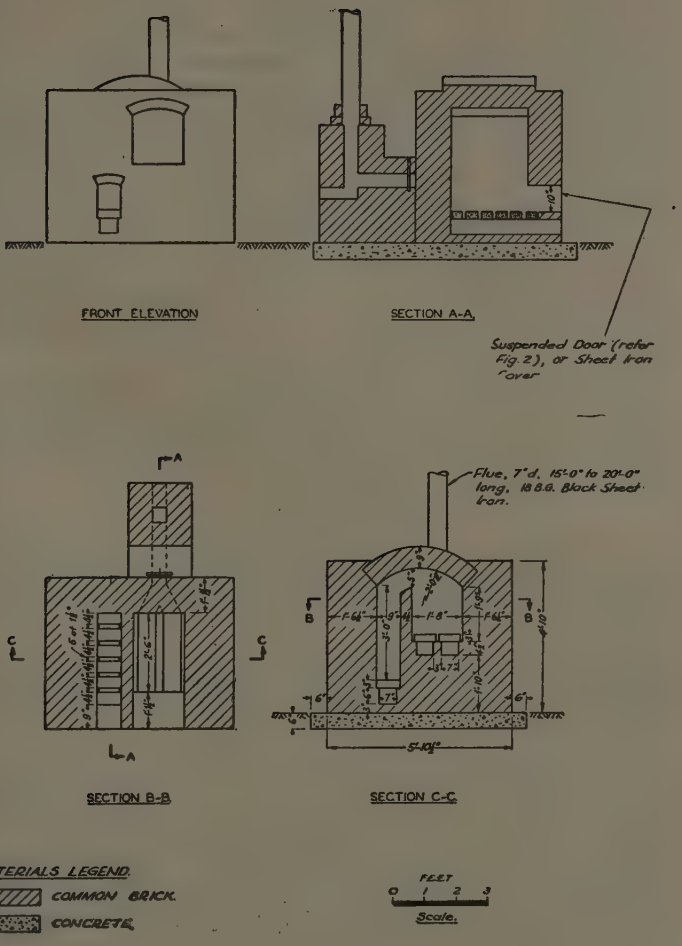


FIG. 3.—Experimental kiln, wood-fired. For low temperature work no lining is necessary. If intended for higher temperature burning or glazing, lining as shown in Fig. 1 should be used.

* For field testing of raw materials it may be necessary to improvise where bricks are in short supply or unavailable. Where few bricks are available these may be used for the outside lining only and the kiln for the most part may be constructed of rubble with a clay filler, or of mud bricks. On one occasion in Persia where no bricks were available the whole kiln was built by the author from carefully dried mud blocks, and the cracks filled in and covered with clay; with slow preheating such a kiln stood up to fifteen burnings without failure.

for still higher temperatures a high alumina brick lining and the additional use of insulating bricks behind the fire lining are required. The different internal constructions and linings are shown in the illustrations. However, it should be clearly understood that while the details of kiln construction are specific for a particular fuel the linings shown in the illustrations are not necessarily so, but depend upon the working temperature to which the kiln will be subjected. For instance, if the temperature required in the coal-fired kiln is not too high the kiln may be lined as shown for the wood-fired kiln. If, on the other hand, the maximum temperature is required in a wood-fired kiln the lining and insulation shown for the kiln using coal should be incorporated in the wood-fired kiln.

The actual burning chamber is identical for each of the three types of fuel. The same is true for the flues and chimney stocks, although it is necessary to provide a longer fire-lined flue before the gases reach the steel pipe chimney, if very high temperatures are required in the kiln.

The chamber floors are built from clay slabs 3 by 4½ by 19 in., or simply from loosely laid bricks. In order to obtain an even distribution of temperature within the kiln the openings between the slabs or bricks should be larger near the front of the chamber and gradually reduced towards the back.

3. Choice of Fuel

As was pointed out in the previous section, the kiln may be designed for any type of fuel, the choice will depend upon the maximum temperature required or upon the availability of a particular fuel.

However, oil has two distinct advantages over coal and wood. Firstly, higher temperatures may be reached, since the ceiling temperatures are about 1370° C. (2500° F.) with wood, 1500° C. (2700° F.) with coal, and up to 1650° C. (3000° F.) with oil. Secondly, it is easy to handle, and is generally the most suitable.

With the simple method of drip feeding on to a sloped step grate the rate of oil flow may be controlled to give a rate of temperature increase within the furnace, ranging from 5° C. per hour up to 50° C. per hour for low temperatures, and up to 150° C. per hour for high temperatures. To start the fire cotton waste is placed on the floor of the furnace; it acts as a wick when the oil drops upon it. As the temperature rises the step grate is gradually heated, causing the oil falling on it to evaporate and burn immediately. In the final stages the grate becomes red hot, the oil is immediately cracked and the gases derived burn with intense heat. The natural draught is sufficient to ensure the furnace reaching the required temperature.

4. Conclusion

The simplicity of construction and high efficiency of the kiln should make it eminently suitable for general use in either the laboratory or the plant. It should be valuable as an experimental unit for existing works, enabling reliable results to be obtained in a shorter time than is possible when test samples have to be burnt in ordinary production kilns.

NOTES

Division of Tribophysics

The status of the section of Tribophysics has now been raised to that of a Division. Dr. S. H. Bastow will continue as Chief of the New Division.

Building Research Section

The name of the Building Materials Research Section has been changed to Building Research Section.

Recent Publications of the Council

Since the last issue of this *Journal,* the following publications of the Council have been issued:—

Bulletin No. 212.—"The Frictional Properties of Lead-base and Tin-base Bearing Alloys: The Role of the Matrix and the Hard Particles", by D. Tabor, Ph.D.

Previous Bulletins Nos. 145 and 155 gave an account of the frictional properties of alloys of the copper-lead type, which consists of a relatively hard matrix copper in which soft particles of lead are dispersed. The present Bulletin describes an extension of this work to include lead-base and tin-base bearing alloys, which possess soft matrices in which are dispersed hard particles. Measurement of friction at room and elevated temperatures for clean and for lubricated surfaces showed that the hard particles of the bearing alloys played no great part in the basic frictional and wear properties of the alloys. The view is expressed that the frictional behaviour of a white-metal bearing alloy is a function of the properties of the matrix.

Bulletin No. 213.—"Laboratory and Field Tests of Mosquito Repellents", by R. N. McCulloch, B.Sc., B.Sc.Agr., and D. F. Waterhouse, M.Sc.

Tests were made of more than 125 materials for use as repellents against Anopheline and Culicine mosquitoes. The main species used were the two important vectors of disease, *Anopheles punctulatus farauti* and *Aedes aegypti,* and the common pest mosquito of coastal New South Wales, *Aedes vigilax.* The time to the first bite on treated skin was taken as the first indication of efficiency, but in distinguishing between better repellents, attention was paid to the spree with which subsequent biting occurred. Cage tests proved most convenient for selecting the more effective repellents for field testing, but tended to indicate, for better repellents, longer protection than was obtained in field tests. The most effective repellents, giving almost complete protection for 45 to 60 minutes under the most severe conconditions, were dimethyl phthalate, 612 (2–ethylhexane–1, 3–diol), Staway, and oils of *Dacrydium franklinii* (Huon pine), *Melaleuca bracteata, Zieria smithii,* and *Backhousia myrtifolia.* Under similar

conditions Ceylon citronella oil gave protection for no more than 20 minutes. Oils of some of the native plants owe their repellency to their high content of methyl eugenol, but are unsuitable for use because of their irritant effect on the skin.

Dimethyl phthalate proved the most effective and acceptable. It is almost odourless, is non-irritant, and on the whole pleasant to use. Many other synthetic and naturally occurring substances were tested, but gave no sustained protection. Tests on sassafras oils were promising but proved too irritant for use.

Bulletin No. 219.—"Spray Tests against Adult Mosquitoes. 1. Laboratory Spray Tests with Culicine (*Culex fatigans*) Adults," by D. F. Waterhouse, M.Sc. "2. Spray Tests with Anopheline (*Anopheles punctulatus farauti*) Adults," by D. F. Waterhouse, M.Sc., and D. O. Atherton, M.Sc.Agr.

The investigations described in this Bulletin were carried out in 1942 and 1943 to provide a basis upon which to formulate specifications for a spray for use against the mosquito vectors of malaria and dengue fever. When this work was begun, most of the existing information on toxic ingredients for sprays was derived from tests against houseflies. It was soon shown that these results could not be used to formulate anti-mosquito sprays.

Pyrethrum was in such short supply that its use had to be restricted to the control of Anopheline mosquitoes, and it was essential that the minimum concentration consistent with efficiency and a reasonable margin of safety should be determined as quickly as possible. On the basis of the tests carried out a standard for mosquito sprays was decided upon and adopted by the Australian Army. It was used until supplies of DDT became sufficient to reinforce the spray and convert it into an all-purpose one.

Bulletin No. 221.—"Contributions to the Study of the Cell Wall. 4. The Nature of Intercellular Adhesion in Delignified Tissue. 5. The Occurrence, Structure, and Properties of Certain Cell Wall Deformations," by A. B. Wardrop, M.Sc., and H. E. Dadswell, D.Sc.

In the first paper of this Bulletin it is recorded that certain chemical processes, which are generally applied to wood in order to obtain isolated fibres, have been used on thin sections cut from a number of Australian timbers and the affect of the reactions examined using the microscope. Earlier work had indicated that there was apparently some bonding material other than lignin which assisted in holding the individual fibres together. As a result of the present work, however, it is now thought that the adhesion between cells after the removal of lignin is purely mechanical since fibre to fibre separation can be obtained by very slight swelling of the cell walls using dilute alkali.

The slip planes and minute compression failures observed in the cell walls of numerous timbers have been investigated in relation to their optical properties, staining reactions, and chemical behaviour. The relationship of these cell wall deformations in wood to the dislocation marks of certain textile fibres has been stressed. The results

of experiments on the artificial production of such cell wall deformations and some theories regarding their mode of formation and distribution in the living tree have been discussed. From the consideration of their distribution in the tree, it has been suggested that the formation of these features is dependent on the operation of growth stresses during the development of the tree. Further, it has been concluded that while slip planes and minute compression failures are essentially alike in physical form they are not successive stages in failure under compression.

Bulletin No. 226.—"An Ecological Study of the Australian Plague Locust (*Chortoicetes terminifera* Walk.) in the Bogan-Macquarie Outbreak Area, N.S.W.," by L. R. Clark, M.Sc.

This Bulletin describes field investigations carried on in the Trangie District, N.S.W., in order to gain an understanding of the influence of changes in climate, soil, and vegetation on the numbers of the Australian plague locust. Results show that pasture and soil conditions control the production of swarms. Favourable food-shelter areas fortunately comprise only a small percentage of the district.

It is concluded that future attempts at control should be directed towards the prevention of swarm formation by either changing the vegetation or by direct control such as the use of insecticides or by ploughing.

Bulletin No. 227.—"Studies on Perennial Veldt Grass (*Ehrharta calycina* Sm.)," by R. C. Rossiter, B.Sc.(Agric.).

The possibility of using *Ehrharta calycina* as a perennial grass in sheep-raising areas is of particular interest in Western Australia where *Phalaris tuberosa* is of only limited value.

Investigation of seed samples showed the relatively low purity and germination percentages usually encountered. Rapid shedding of the seed makes harvesting difficult. At Perth, maximum seed yields are obtained about seven weeks after the commencement of flowering. Higher seed yields are secured by leaving the seed head attached to the whole stem than by stripping. A non-shedding type of *E. calycina* has been isolated and work now in progress is aimed at selecting desirable grazing types.

The poor survival of the grass in grazed pastures is largely due to its great palatability which leads to selective over-grazing. Attempts are being made to overcome this by suitable pasture management.

Bulletin No. 228.—"Ecological Observations on the Small Plague Grasshopper (*Austroicetes cruciata* Sauss.), in the Trangie District, Central Western New South Wales," by L. R. Clark, M.Sc.

The investigation described in this Bulletin was undertaken in the Trangie District at the same time as the more important investigations on *Chortoicetes terminifera,* which have been conducted in that area for some years.

Austroicetes cruciata is most numerous in areas containing a patchwork of bare compact ground and pasture. The bare ground is needed for egg laying and the pasture for food and for the provision of shelter during the hottest part of the day; they must be close together so that the grasshoppers do not have to move many yards to get from one to the other. At Trangie in years of average rainfall, the pasture contains the necessary bare areas only where patchy soil erosion has occurred. Thus the grasshopper is unlikely to become a serious problem in this district, unless heavy grazing results in more extensive soil erosion.

Bulletin No. 229.—"Studies in Cement-Aggregate Reaction. 1. Australian Aggregates and Cements," by A. R. Alderman, D.Sc., Ph.D., A. J. Gaskin, M.Sc., R. H. Jones, B.Sc., and H. E. Vivian, B.Sc.Agr. "II.—The Effect of Alkali Movement in Hardened Mortar," by H. E. Vivian, B.Sc.Agr. "III.—The Effect of Void Space on Mortar Expansion," by H. E. Vivian, B.Sc.Agr. "IV.—The Effect of Expansion on the Tensile Strength of Mortar," by H. E. Vivian, B.Sc.Agr. "V.—The Effect of Void Space on the Tensile Strength Changes of Mortar," by H. E. Vivian, B.Sc.Agr. "VI.—The Effect of Carbon Dioxide," by A. J. Gaskin, M.Sc.

In 1942 the Cement and Concrete Association of Australia agreed to support, for five years, the Council's research programme on cement and concrete. The agreement has recently been extended for a further five years.

The present Bulletin describes part of the main project during the first five years. The investigations have shown which aggregate materials to avoid in concrete structures. Some materials which it was proposed to use in certain large concrete structures have been proved unsuitable, thus costly failures in future construction can be avoided. For these reasons the work is already returning large dividends.

In addition to classifying available aggregate materials, rapid methods for identifying unsuitable aggregates have been developed.

Bulletin No. 230.—"The Preparation and Properties of Aluminium Fluoride," by T. R. Scott, M.Sc.

Aluminium fluoride is one of the minor constituents added to the electrolytic cells during the production of metallic aluminium, some thousands of tons being required annually because of the very large output of the metal. No natural deposits of this compound are known and it must therefore be manufactured, not only for the aluminium industry, but also for use in ceramics and metallurgy.

In this Bulletin, methods which have been used or proposed for the manufacture of aluminium fluoride are critically reviewed and a choice made of the most suitable method for producing a high-grade material. The selected method utilizes hydrofluoric acid and aluminium hydroxide (or the metal itself) as the sources of fluorine and aluminium respectively. Problems associated with the preparation

of solutions of aluminium fluoride from these reagents are discussed and include difficulties arising from corrosion, the use of impure reagents, and the metastable nature of the solutions. Hydrated aluminium fluoride is recovered from the solutions in 80-85 per cent. yield by a process of high-temperature crystallization, in the presence of acid and seed crystals.

The aluminium fluoride produced contains less than 0·3 per cent. of water, 0·1 per cent. of silica, and approximately 5 per cent. of alumina. No other impurities are present in significant amounts.

Bulletin No. 235.—"The Algal Genus *Gracilaria* in Australia," by Valerie May, M.Sc.

In the survey of this genus, all available herbarium material in Australia, and some material in New Zealand, together with other exotic specimens have been examined.

It is shown that a series of polytypic species of *Gracilaria* occurs in Australian waters. These species and their forms are described discussed, and compared. Some species have been reduced to subspecific status, and other forms are described as new. Forms described as new are as follows: *G. confervoides* f. *ecortica* and f. *tumida, G. lichenoides* f. *complanata, G. Textorii* f. *tenuis, G. secundata* f. *pseudoflagellifera* and f. *compacta, G. Harveyana* f. *nana.* Where possible, the relationships between Australian and various exotic species or forms are suggested. Keys to the Australian species and forms of *Gracilaria* are given.

"A Textbook of Radar."—A collective work by the staff of the Radiophysics Laboratory, C.S.I.R.

That the physicists of Australia had made material contributions to the field of electrical science is well known. Relaxation of military secrecy has made it possible to publish the work of the past eight years. The Division of Radiophysics has taken this opportunity to compile "A Textbook of Radar" embodying its principle and technique.

The opening chapters cover the historical development of radar and the general theory of shortwave propagation. A chapter devoted to the design and characteristics of the magnetron is followed by a study of the use of the triode valve in pulsed operation and in radar modulation. Microwave transmission theory and resonator techniques are fully dealt with and should prove valuable to those wishing to extend their knowledge of this phase of radiophysics. The important radar components, viz. aerials, receivers, amplifiers, converters, etc. are described. Other chapters deal with radar in action on land, at sea, and in the air. Radar navigation and its application to modern problems in civil aviation is covered by the final chapter.

The book is well produced. The diagrams and plates are profuse and clear.

(This book is not being distributed by C.S.I.R., but copies are obtainable from the publishers, Angus and Robertson Ltd., Sydney. Price 50s.)

Forthcoming Publications of the Council

At the present time, the following future publications of the Council are in the press:

Bulletin No. 223.—"Report of Marine Borer Survey in New Guinea Waters," by A. W. Shillinglaw, B.Sc., Dip.For., and D. D. Moore, B.Sc., A.S.T.C.

Bulletin No. 231.—"Mint Weed, *Salvia reflexa* Hornem. Present Distribution and Status in Australia," by R. Roe, B.Sc.(Agric.), and N. H. Shaw, B.Agr.Sc.

Bulletin No. 232.—"Guide to the Medicinal and Poisonous Plants of Queensland," by L. J. Webb, B.Sc.

Bulletin No. 233.—"A Soil Survey of the Hundred of Seddon and Part of the Hundred of MacGillivray, Kangaroo Island, South Australia, including also Portions of the Hundreds of Cassini and Duncan," by K. H. Northcote, B.Agr.Sc., and B. M. Tucker, B.Sc.

Bulletin No. 234.—"Mineral Deficiency in Plants on the Soils of the Ninety-mile Plain in South Australia. Part 2," by D. S. Riceman, M.Sc., B.Agr.Sc.

Bulletin No. 236.—"Observations on the Plant Communities at "Bundemar," Trangie District, New South Wales, in Relation to *Chortoicetes terminifera* (Walk.) and *Austroicetes cruciata* (Sauss.)," by L. R. Clark, M.Sc.

Bulletin No. 237.—"Heating in Stored Wheat. I. Respiration of Dry Grain, Insect Respiration, and Temperature and Moisture Effects," by Joan Milthorpe, B.Sc., and R. N. Robertson, B.Sc., Ph.D. "II. Heat Production, Heat Conductivity, and Temperature Rise in Grain in the Presence and Absence of Insects," by R. N. Robertson, B.Sc., Ph.D. "III. Two Years' Temperature Records of Dry Grain in a Concrete Silo," by R. N. Robertson, B.Sc., Ph.D., and Joan Milthorpe, B.Sc.

Bulletin No. 238.—"Non-parasitic Disorders of Australian Apple Fruits," by W. M. Carne.

Bulletin No. 239.—"Foundry Sand Resources of New South Wales," by H. A. Stephens, M.Sc., and H. F. Whitworth, M.Sc.

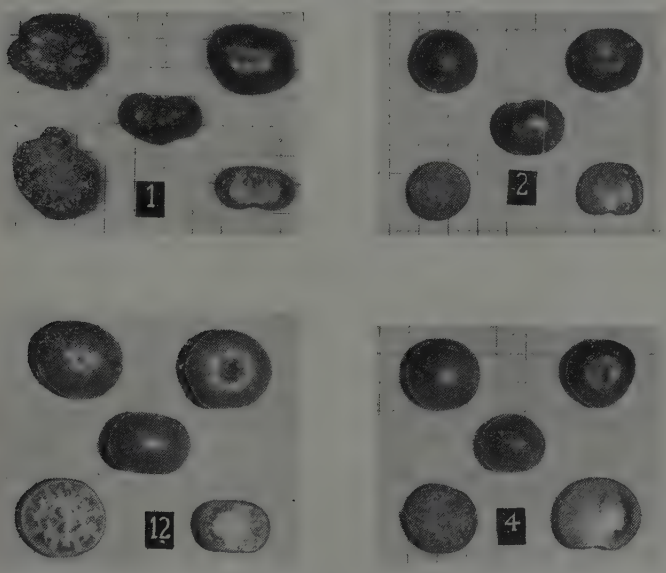
Bulletin No. 240.—"Studies on Dietary and Other Factors Affecting the Serum-Calcium Levels of Sheep," by M. C. Franklin, M.Sc., Ph.D., R. L. Reid, and I. L. Johnstone, B.V.Sc.

Bulletin No. 241.—"An Australian Phytochemical Survey. I. Alkaloids and Hydrocyanic Acid in Queensland Plants," by L. J. Webb, B.Sc.

Bulletin No. 242.—"The Age, Rate of Growth, and General Life-history of the Australian Pilchard (*Sardinops neopilchardus*) in New South Wales Waters," by M. Blackburn, M.Sc.

"Handbook of Australian Pelagic Tunicates," by Harold Thompson, M.A., D.Sc.

Some Studies in the Growth of Tomato Plants and Comparison of Tomato Varieties Grown under Irrigation. (See page 99.)



Typical fruits of tomato varieties showing whole fruit from three aspects, and horizontal and vertical sections. The fruits were photographed against a background of 1-inch squares.

1 = Adelaide Dwarf Red.
2 = Tatura Dwarf Glove
12 = H.E.S. 927M.
4 = Pearson 29–17.

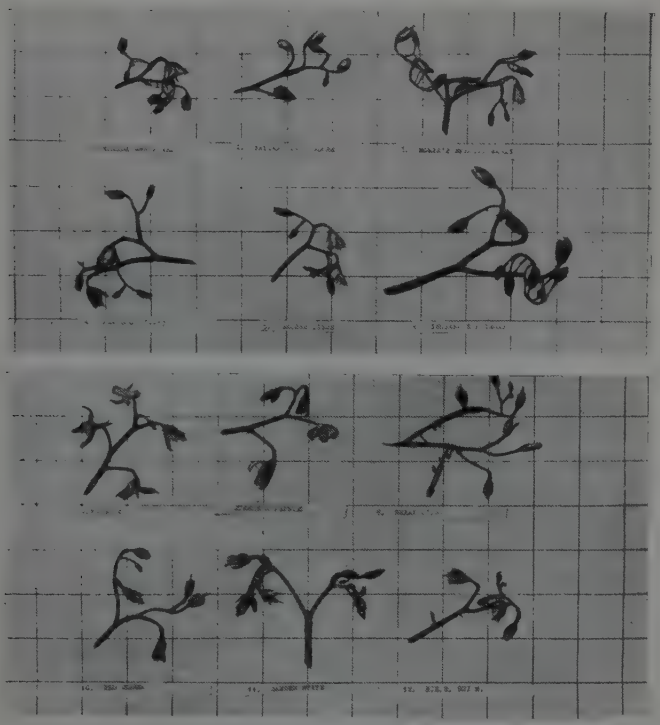
PLATE 2

Some Studies in the Growth of Tomato Plants and Comparison of Tomato Varieties Grown under Irrigation.
(See page 99.)

Typical leaves of twelve varieties of tomato against a background of 1-inch squares.

1 = Adelaide Dwarf Red.
2 = Tatura Dwarf Globe.
3 = Morse's Special Early.
4 = Pearson 29–17.
5 = Grosse Lisse.
6 = Indiana Baltimore.
7 = Riverside.
8 = Stemless Pennred.
9 = Break O'Day.
10 = Red Cloud.
11 = Garden State.
12 = H.E.S. 927M.

Some Studies in the Growth of Tomato Plants and Comparison of Potato Varieties Grown under Irrigation.
(See page 99.)

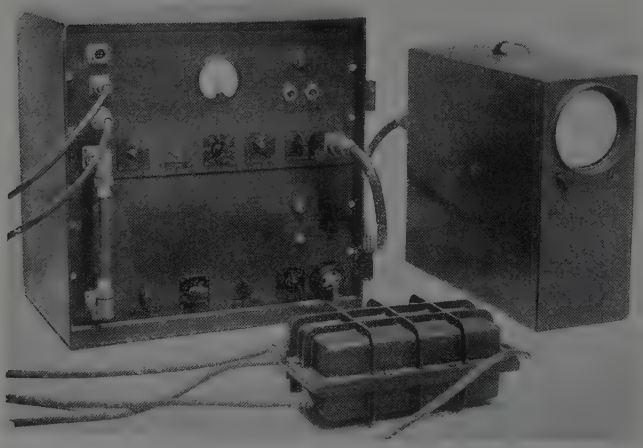


Typical blossom clusters of twelve varieties of tomato against a background of 1-inch squares.

1 = Adelaide Dwarf Red.
2 = Tatura Dwarf Globe.
3 = Morse's Special Early.
4 = Pearson 29–17.
5 = Grosse Lisse.
6 = Indiana Baltimore
7 = Riverside.
8 = Stemless Pennred.
9 = Break O'Day.
10 = Red Cloud.
11 = Garden State.
12 = H.E.S. 927M.

PLATE 4

An Electronic Device for Measuring Mechanical Phenomena.
(See page 141.)



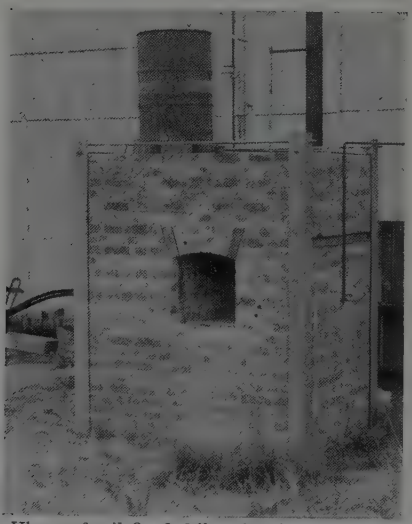
Complete unit as supplied to Design Division.

An Experimental Kiln for Ceramic Ware. (See page 160.)

Side view of Building Materials Research oil-fired kiln at Highett.

PLATE 6

An Experimental Kiln for Ceramic Ware. (See page 160.)



View of oil-fired kiln showing furnace and charge openings.

View of oil-fired kiln showing charge opening and thermocouple leads from the furnace.

J. J. Gourley, Government Printer, Melbourne.

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